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(12) **United States Patent**
Fujiyoshi et al.

(10) **Patent No.: US 8,646,424 B2**
(45) **Date of Patent: Feb. 11, 2014**

(54) **VARIABLE VALVE TIMING DEVICE**

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(73) Assignee: **Denso Corporation**, Kariya (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 243 days.

(21) Appl. No.: **13/309,897**

(22) Filed: **Dec. 2, 2011**

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(30) **Foreign Application Priority Data**

Jan. 20, 2011 (JP) 2011-10097

(51) **Int. Cl.**
F01L 1/34 (2006.01)

(52) **U.S. Cl.**
USPC **123/90.17**

(58) **Field of Classification Search**
USPC 123/90.12, 90.15, 90.17, 90.33, 90.34; 464/160, 161; 137/625.25, 625.26
See application file for complete search history.

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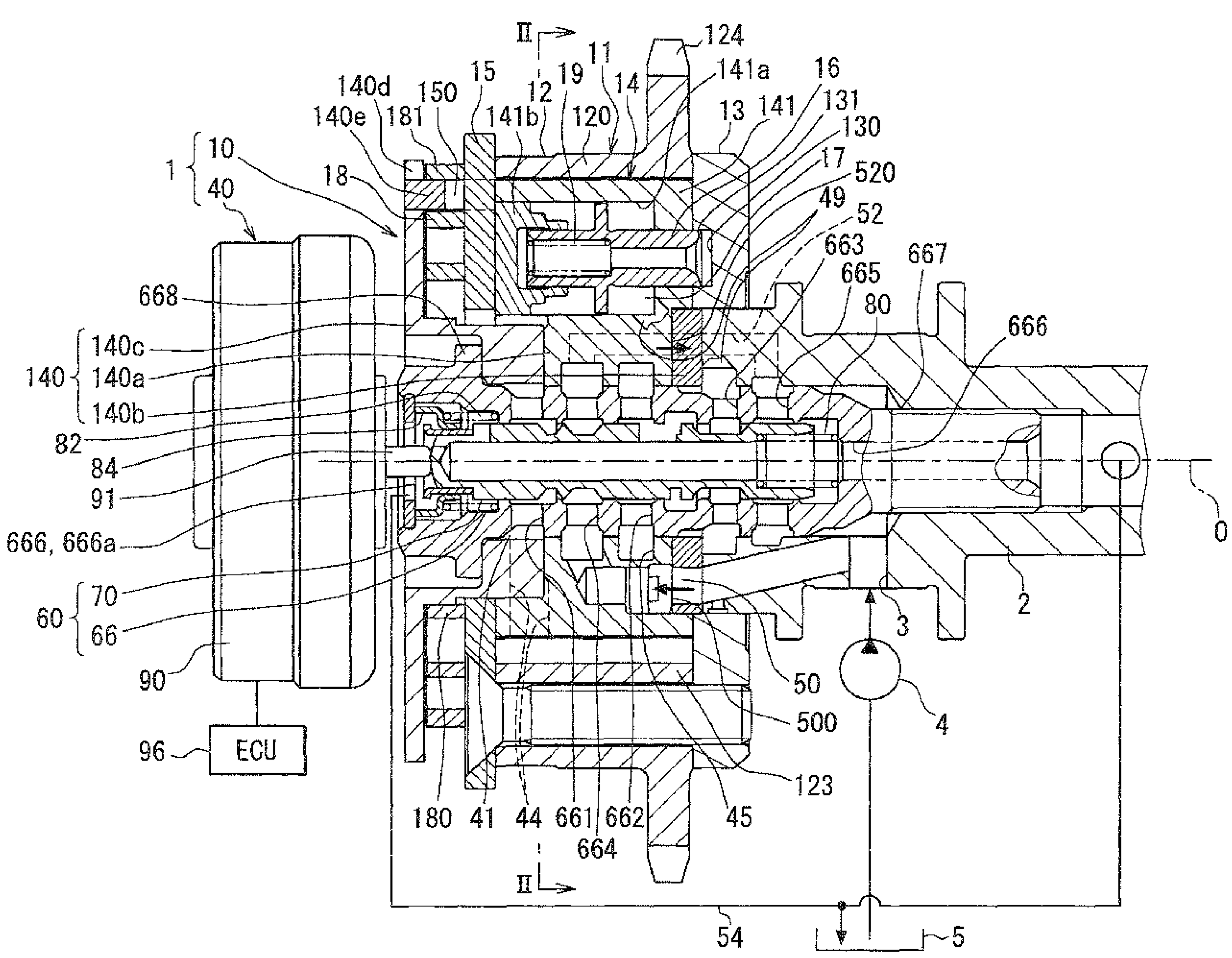
Assistant Examiner — Daniel Bernstein
(74) *Attorney, Agent, or Firm* — Nixon & Vanderhye PC

(57) **ABSTRACT**

A variable valve timing device includes a control valve for switching fluid communication among ports. The control valve includes a sleeve, a spool, a movable member, and resilient members. A first resilient member pushes the spool in both of the regions. A second resilient member acts on the spool via the movable member engaged with the spool in an advancing region. In a lock region, the movable member rests on the sleeve to enable the spool to move freely from the second resilient member. As a result, force acting on the spool can be restricted in the lock region. The movable member is supported from a radial inside by the spool and is radially distanced from the sleeve. As a result, it is possible to reduce a sliding resistance acting on the movable member.

12 Claims, 20 Drawing Sheets



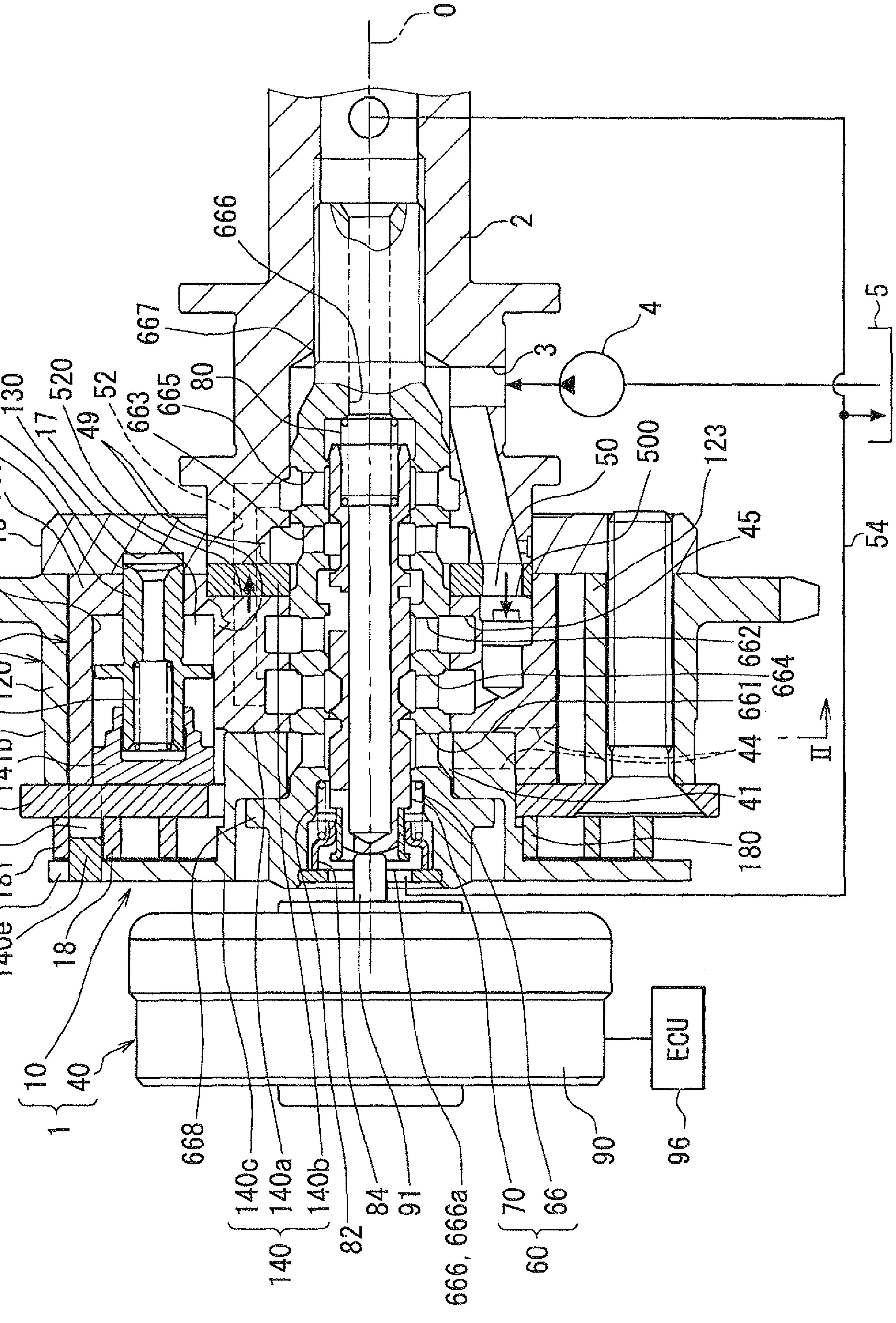


FIG. 1

FIG. 2

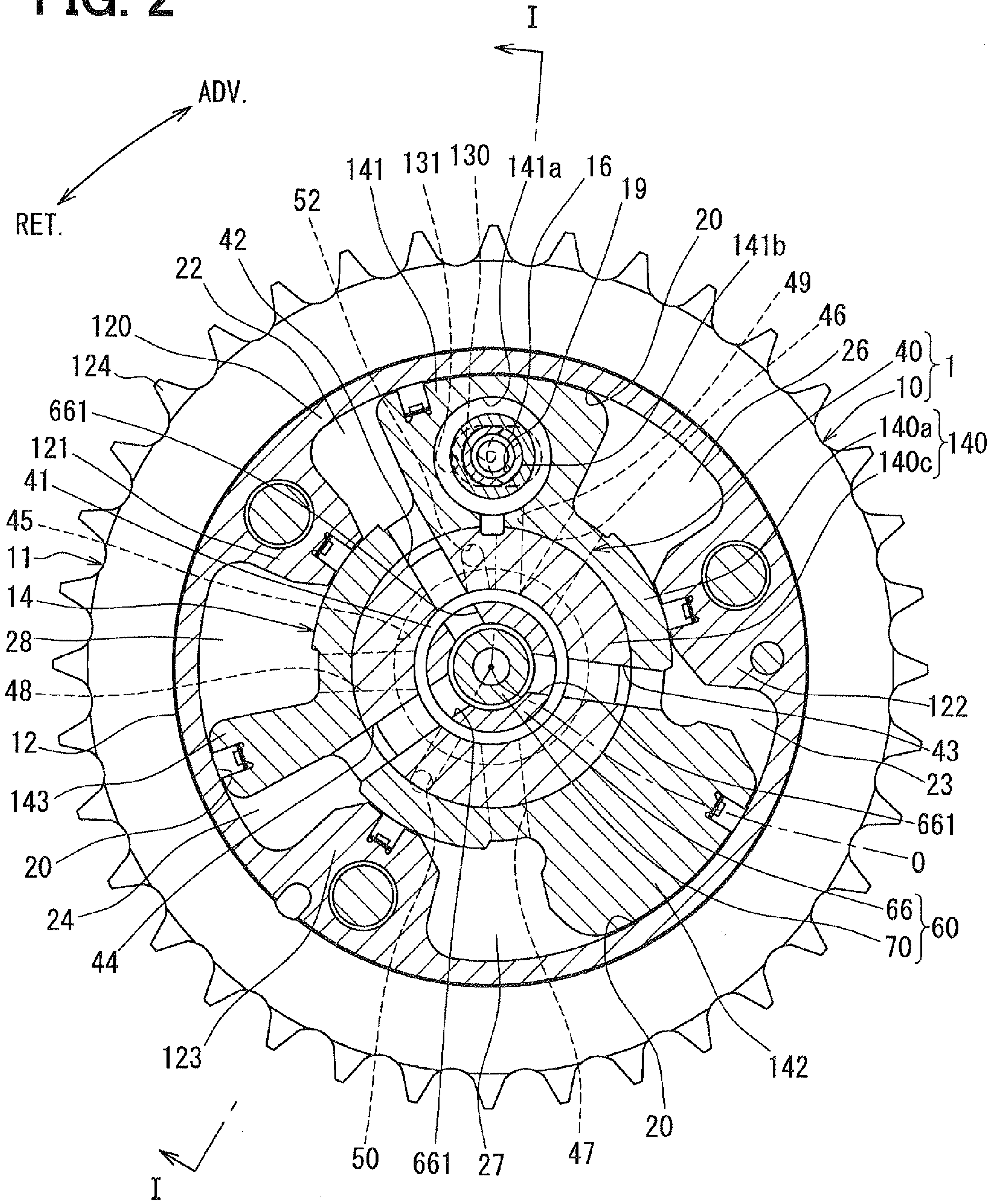

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FIG. 3

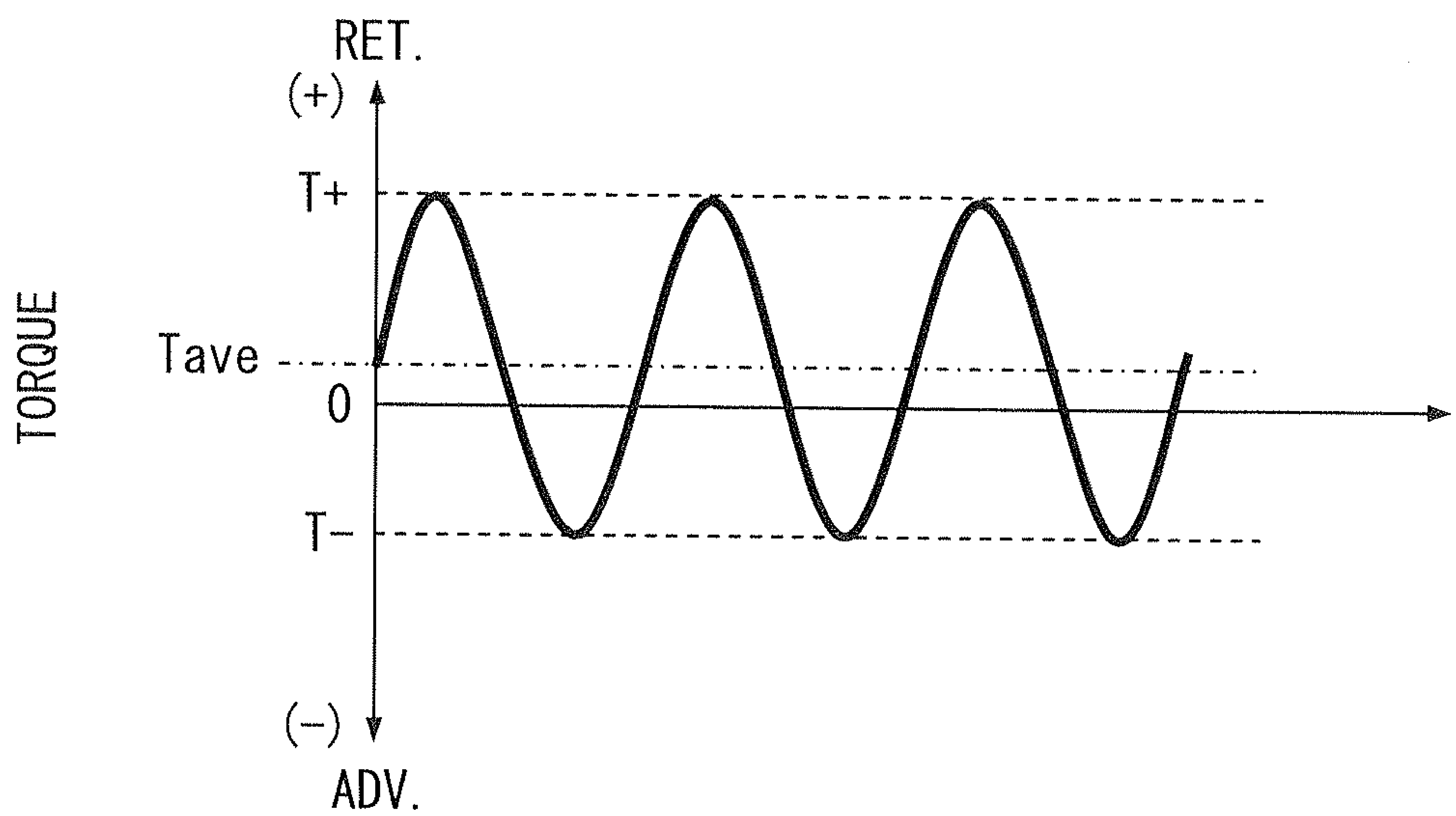
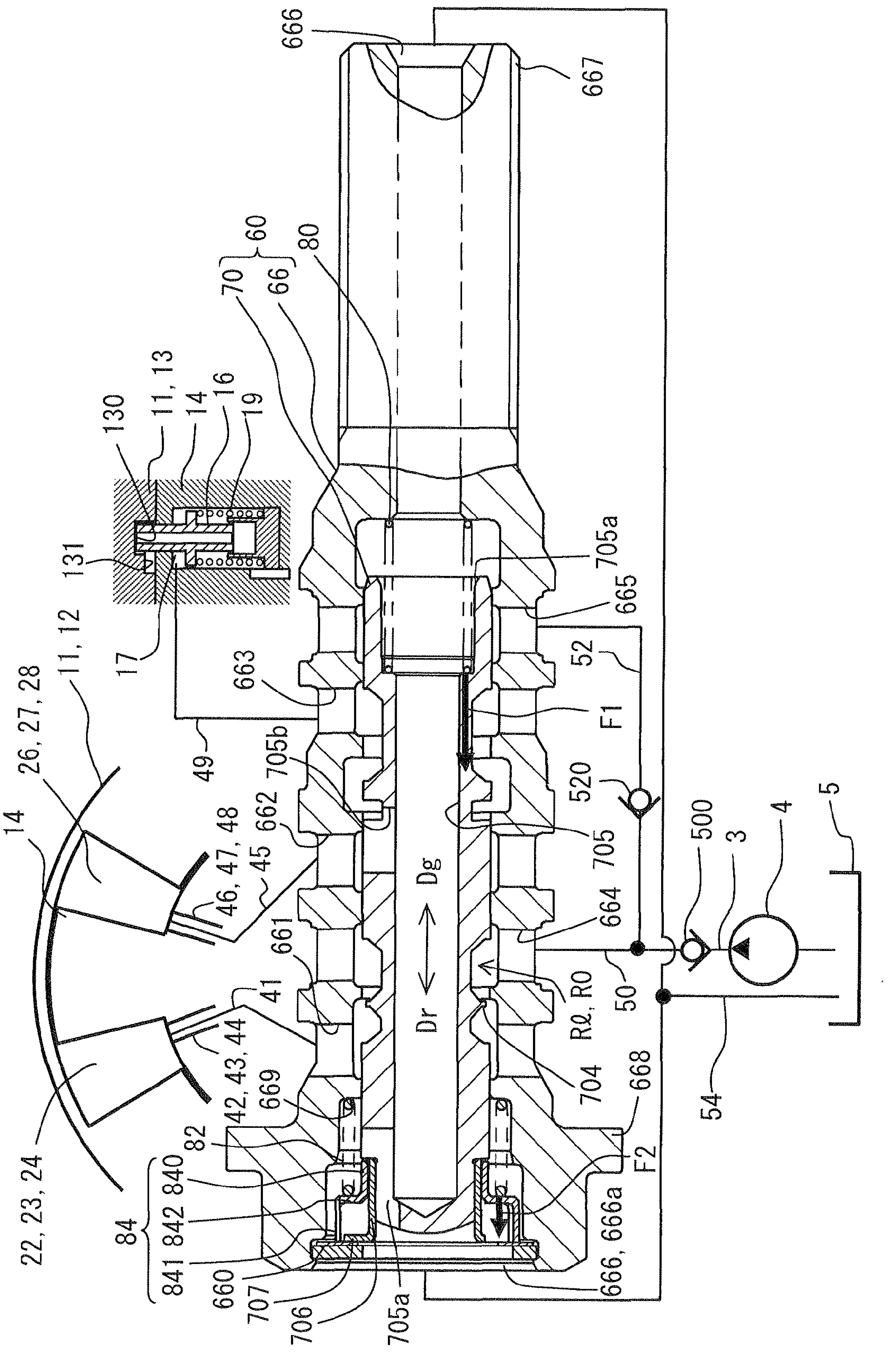


FIG. 4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Rℓ, R0
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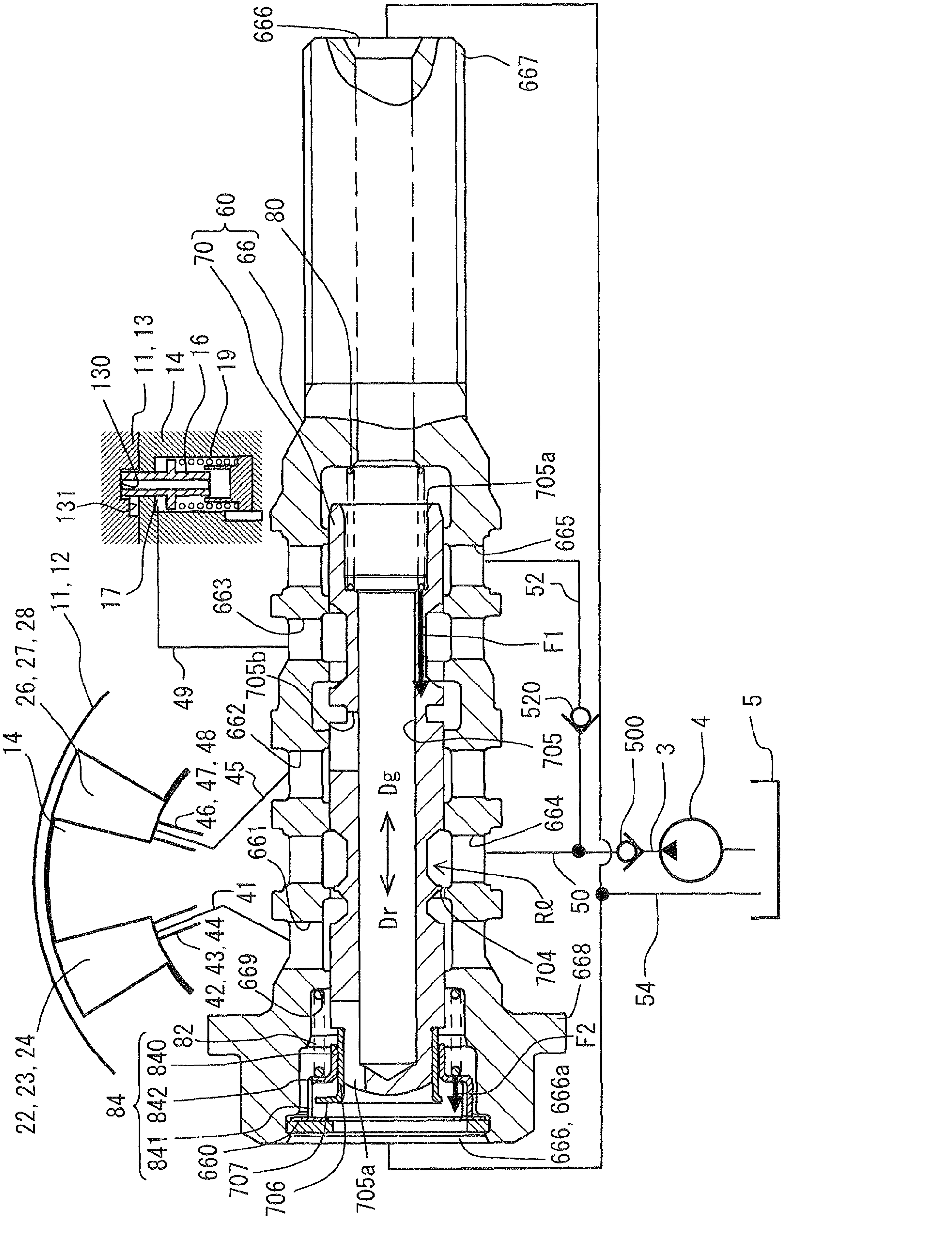
FIG. 5



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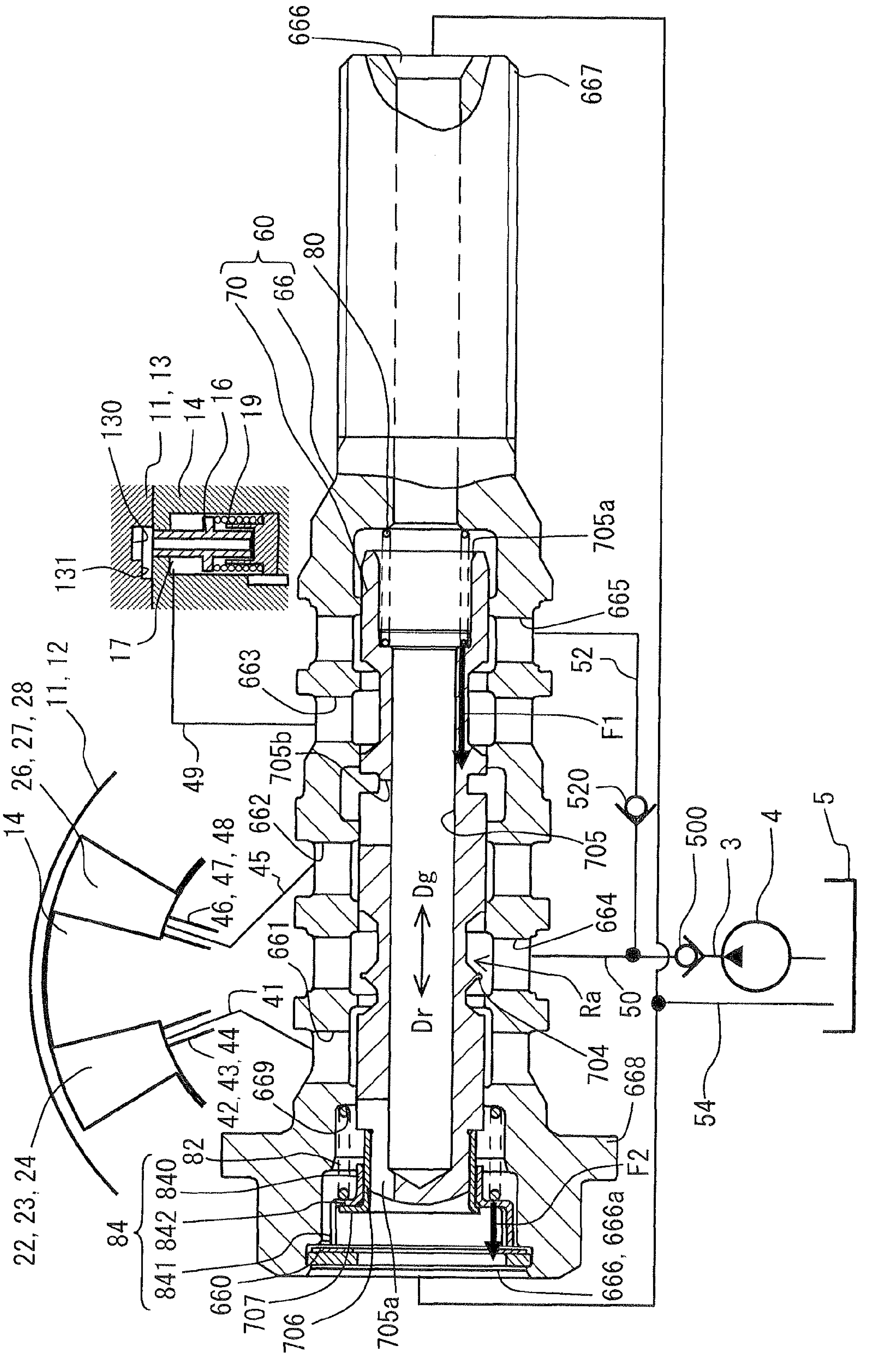
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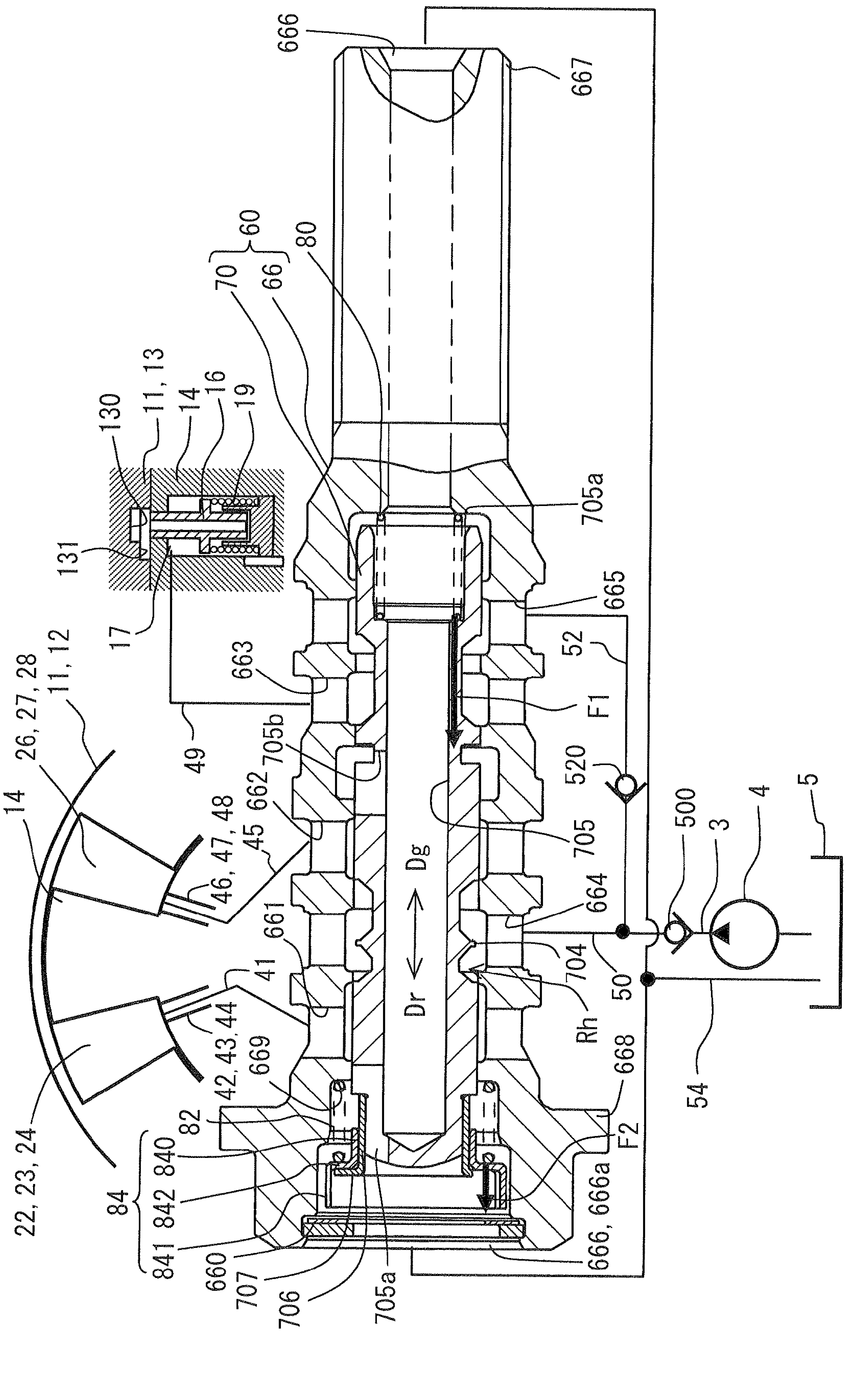
FIG. 6

FIG. 7



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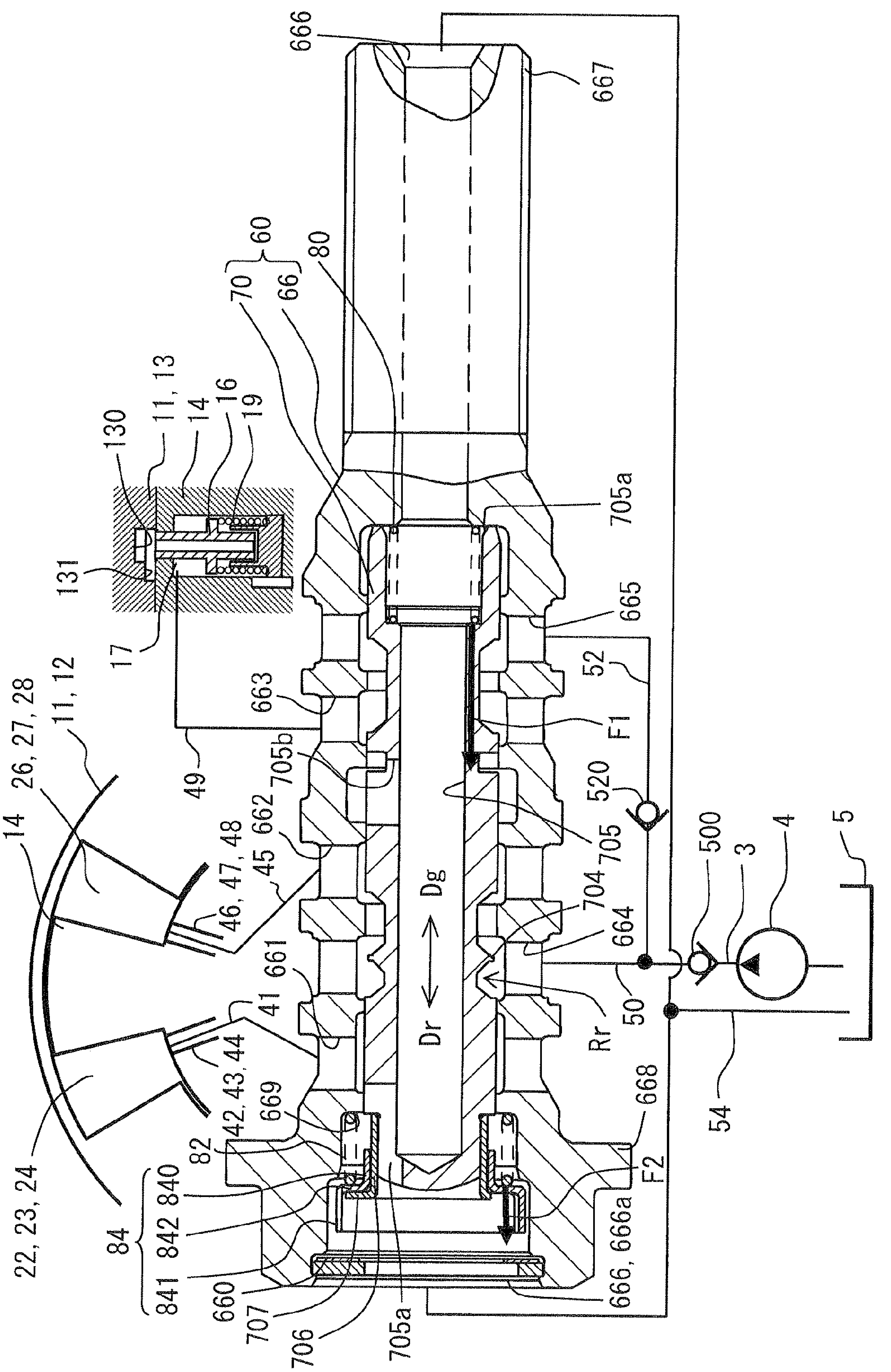
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FIG. 8

FIG. 9A

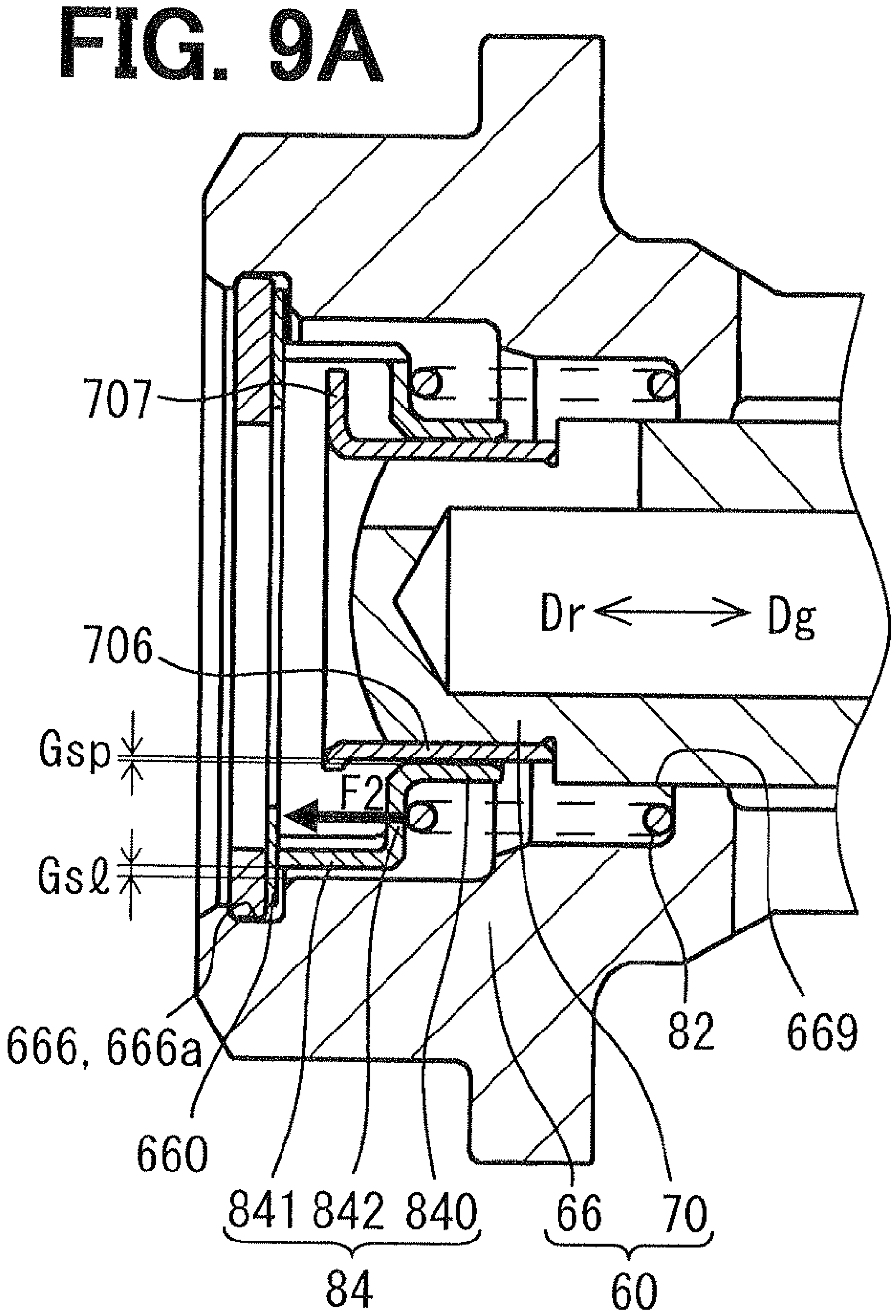
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FIG. 9B

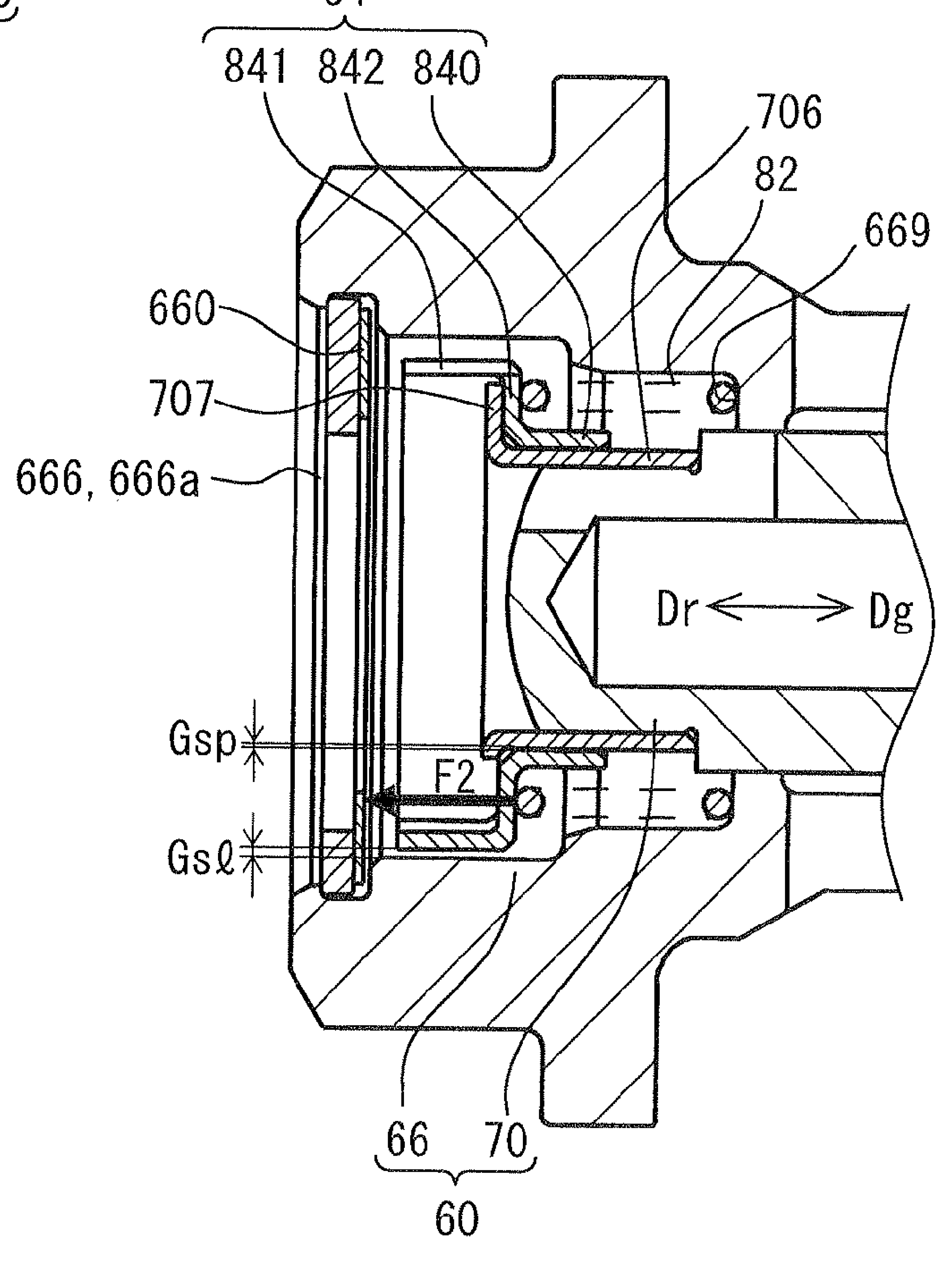
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FIG. 10A

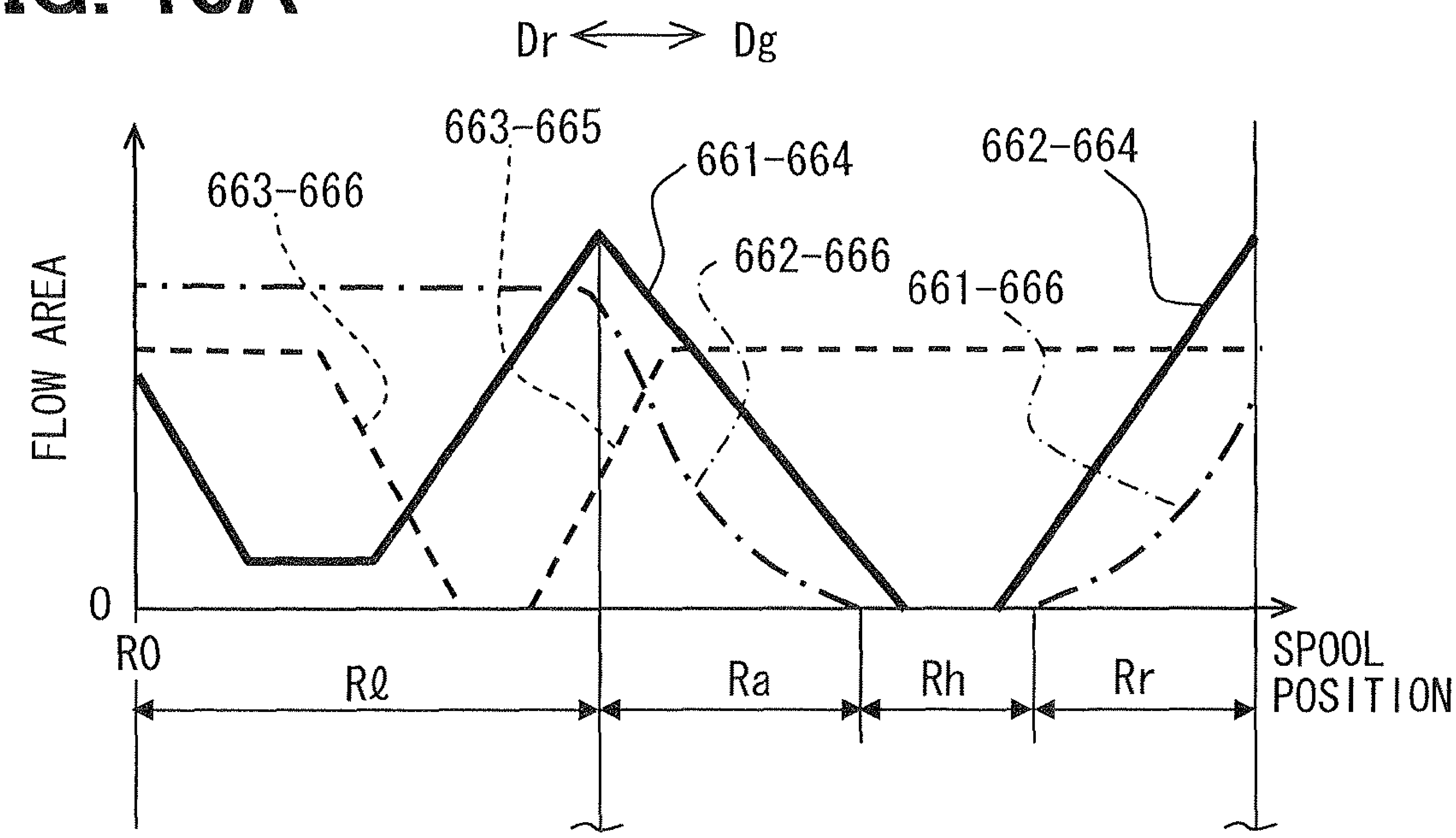


FIG. 10B

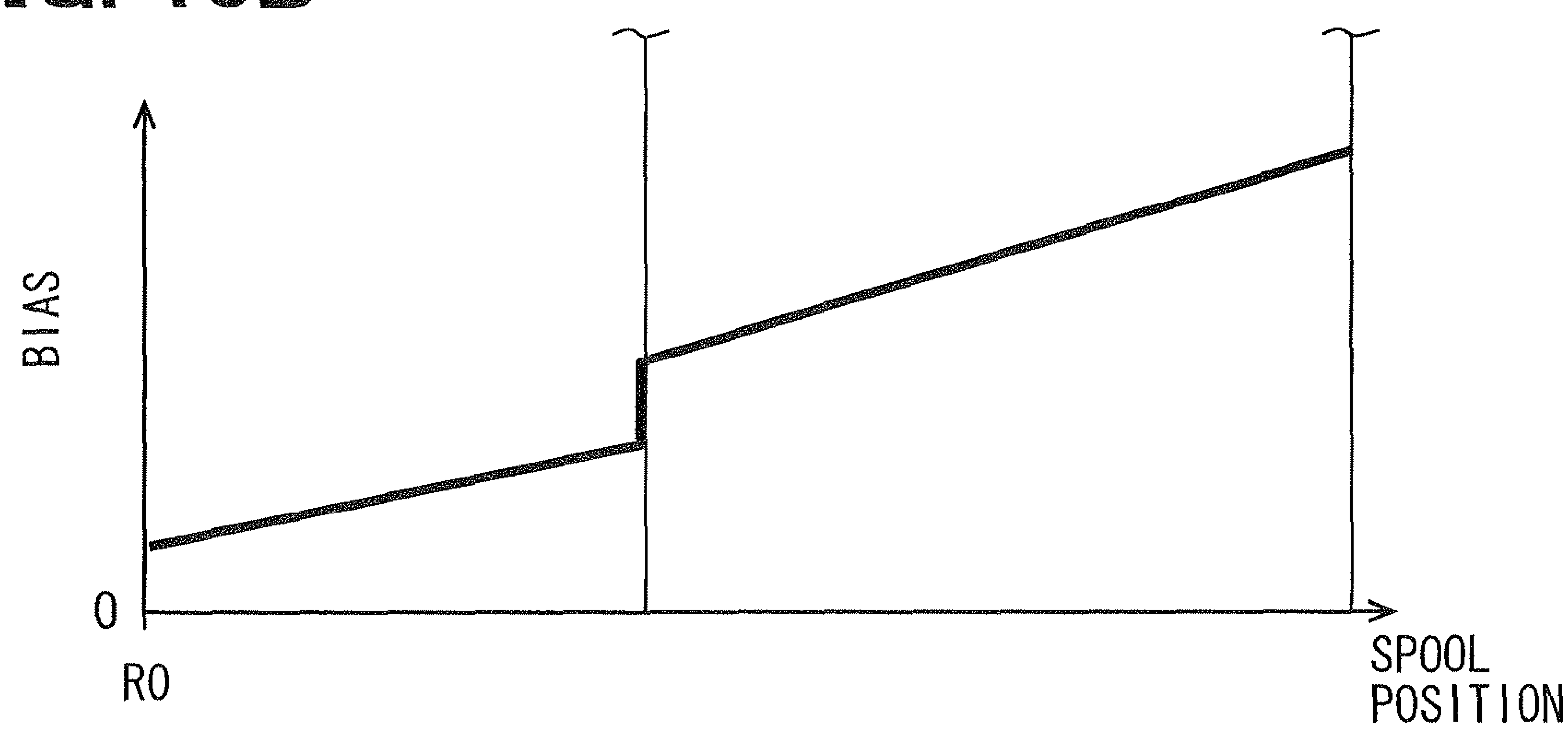
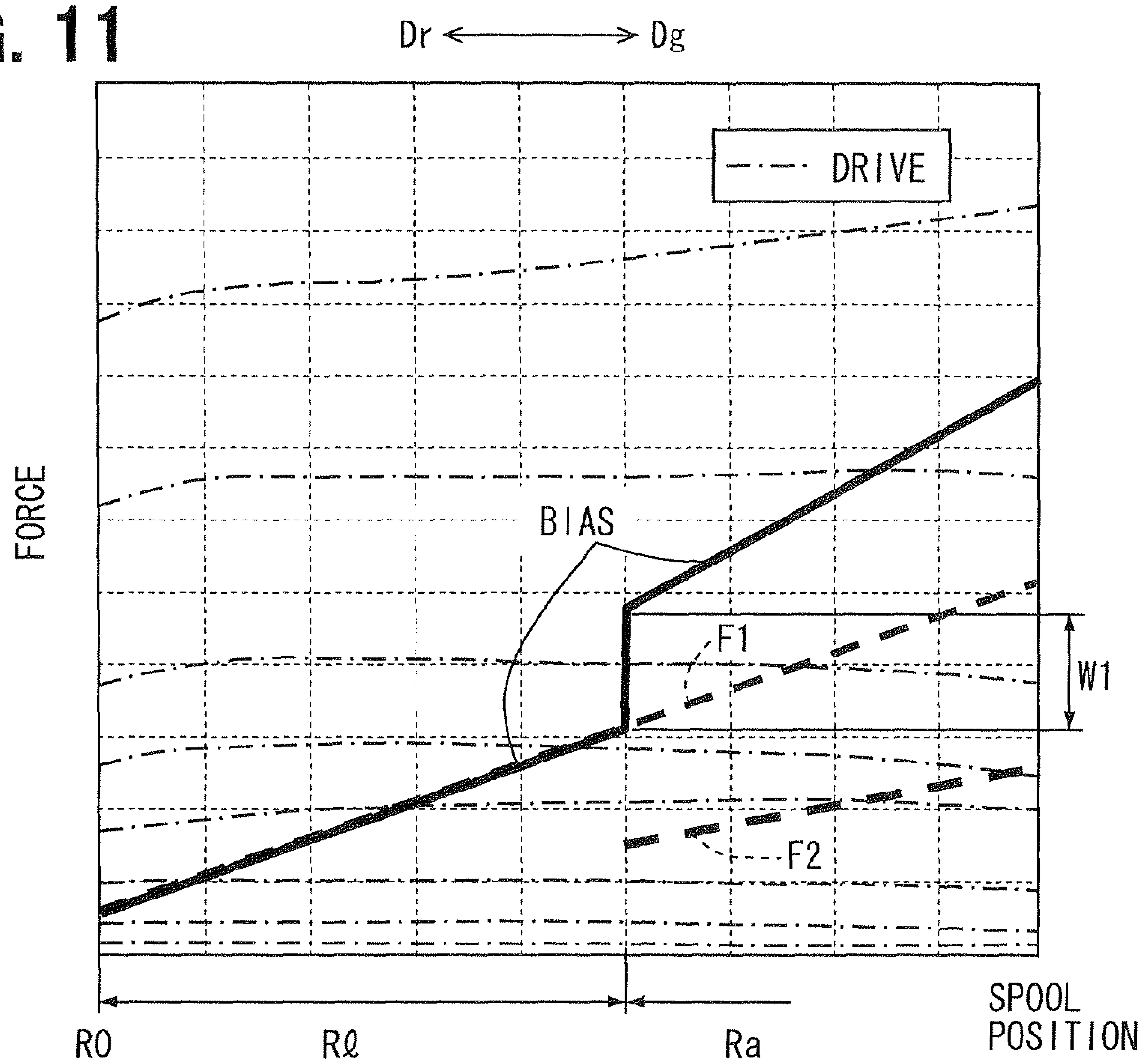


FIG. 11



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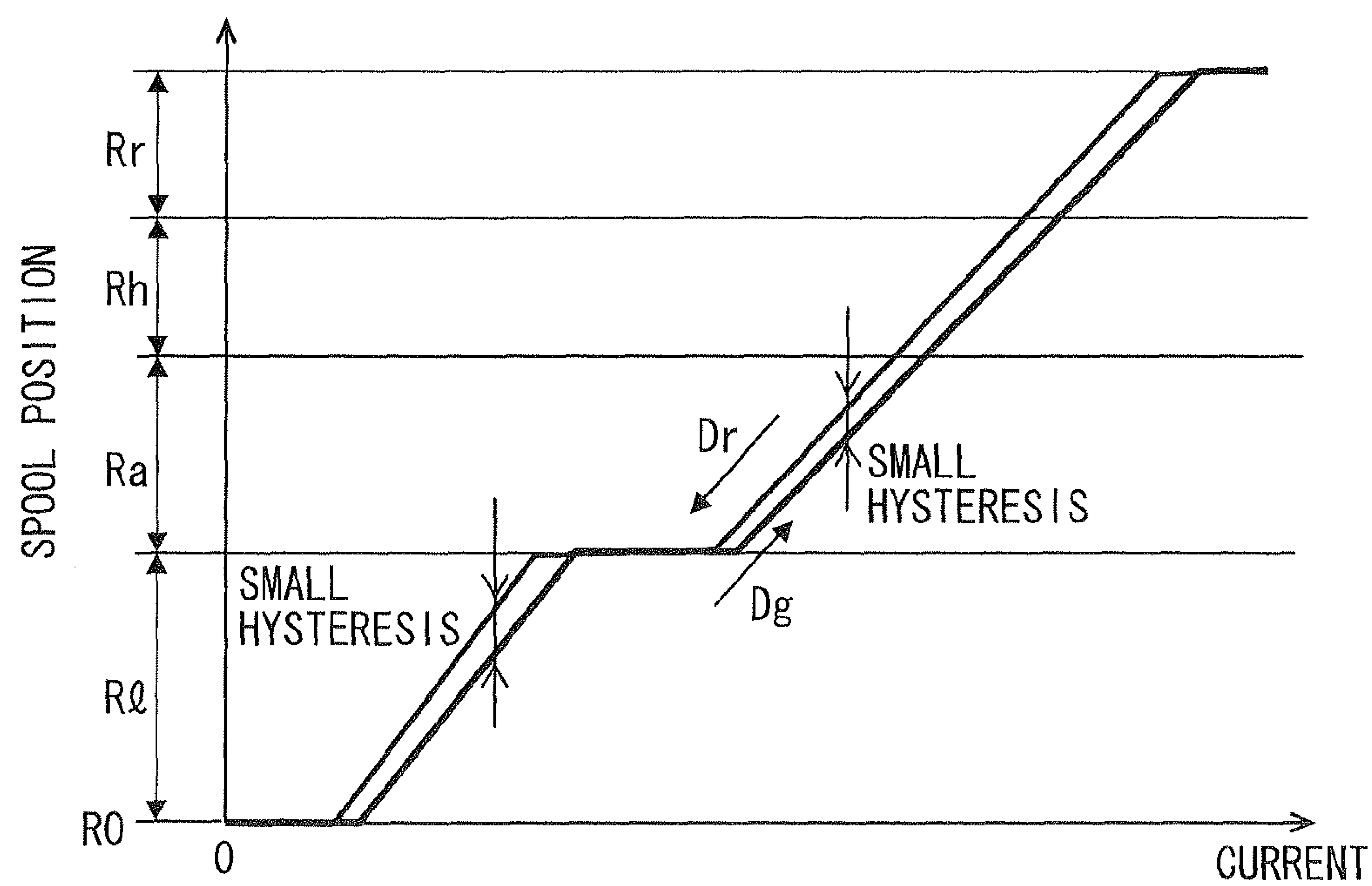
SPOOL POSITION

FIG. 12



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SPOOL POSITION
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SMALL HYSTERESIS
SMALL HYSTERESIS
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CURRENT

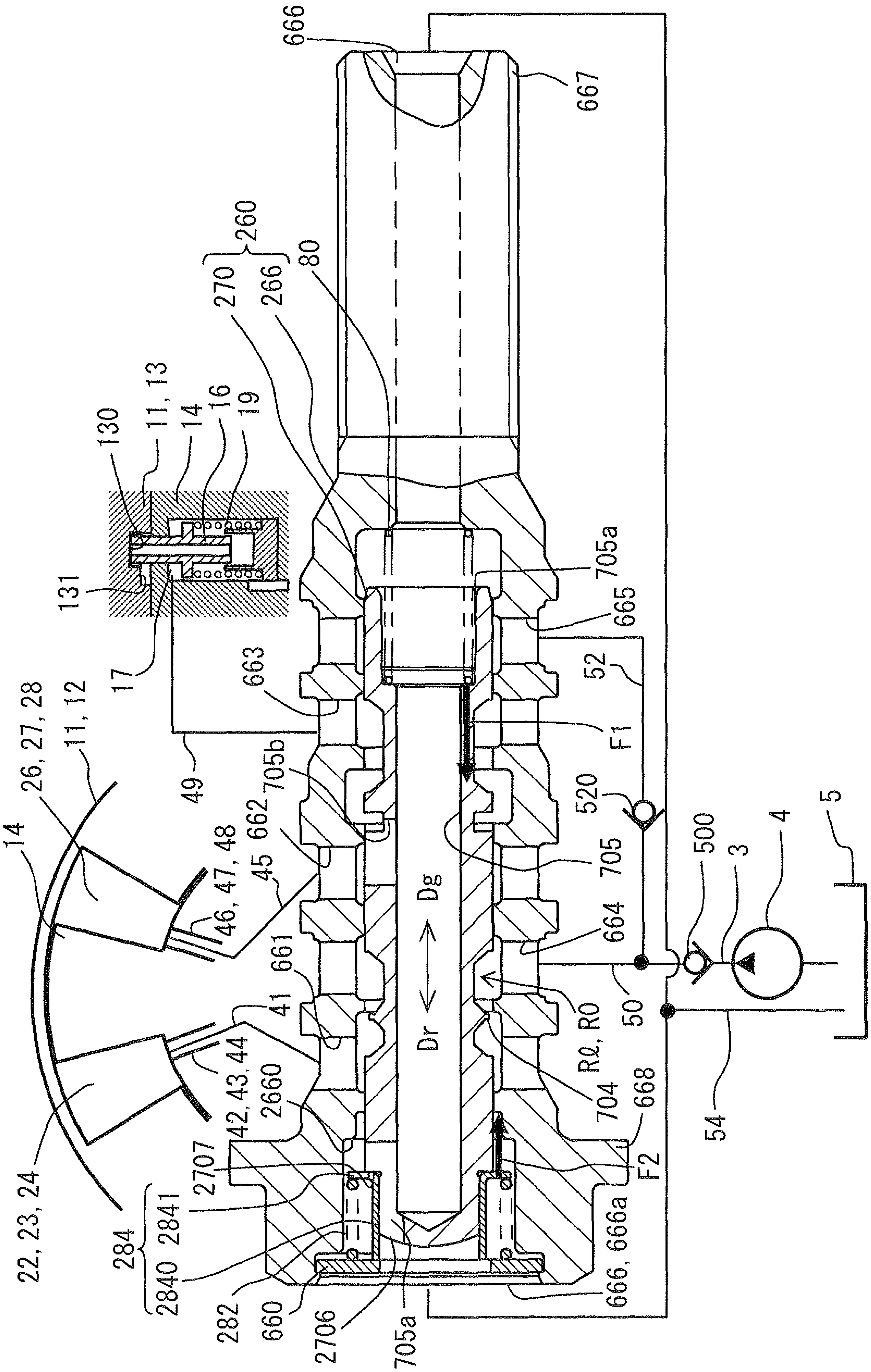
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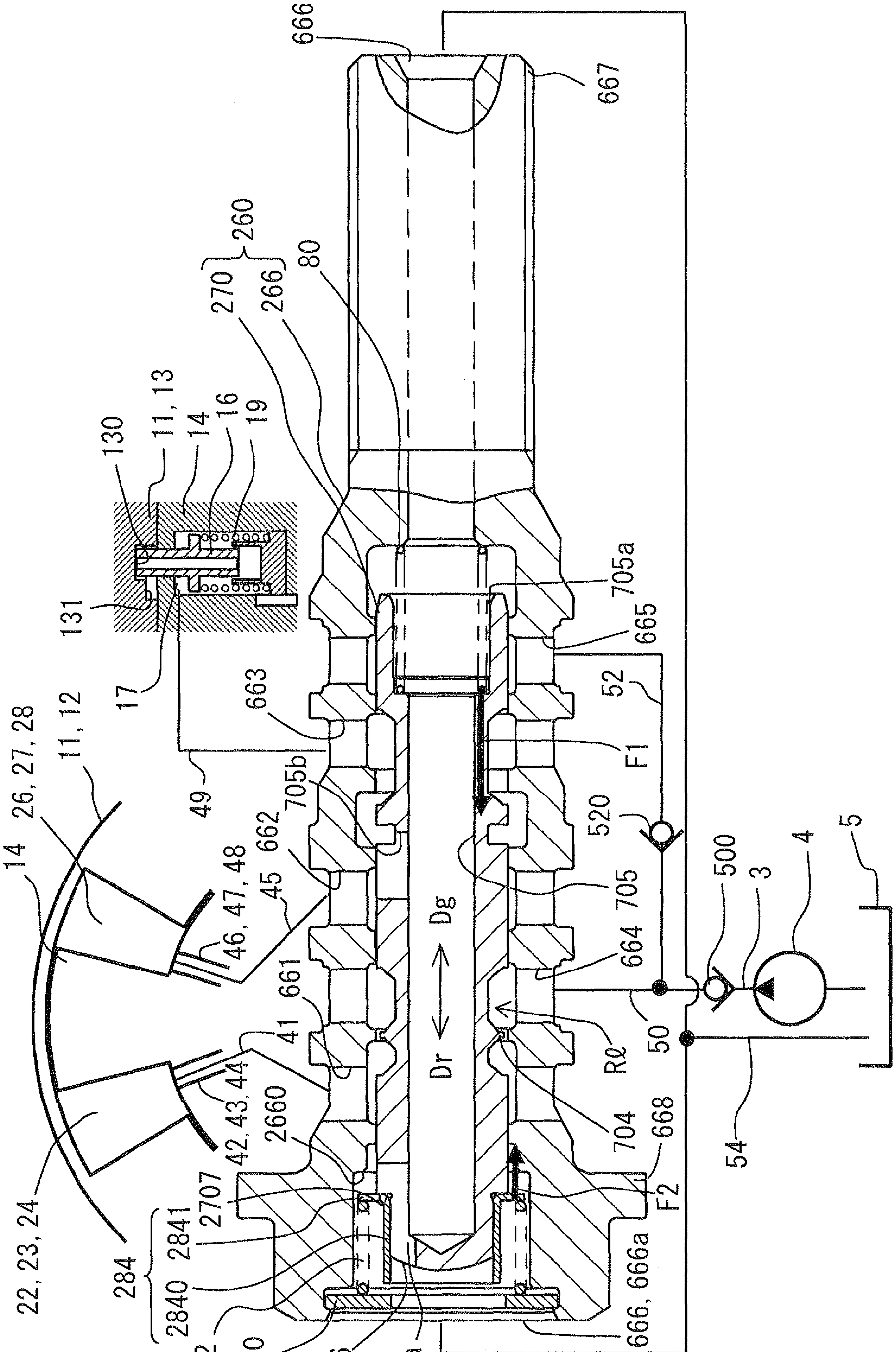
FIG. 13

FIG. 14



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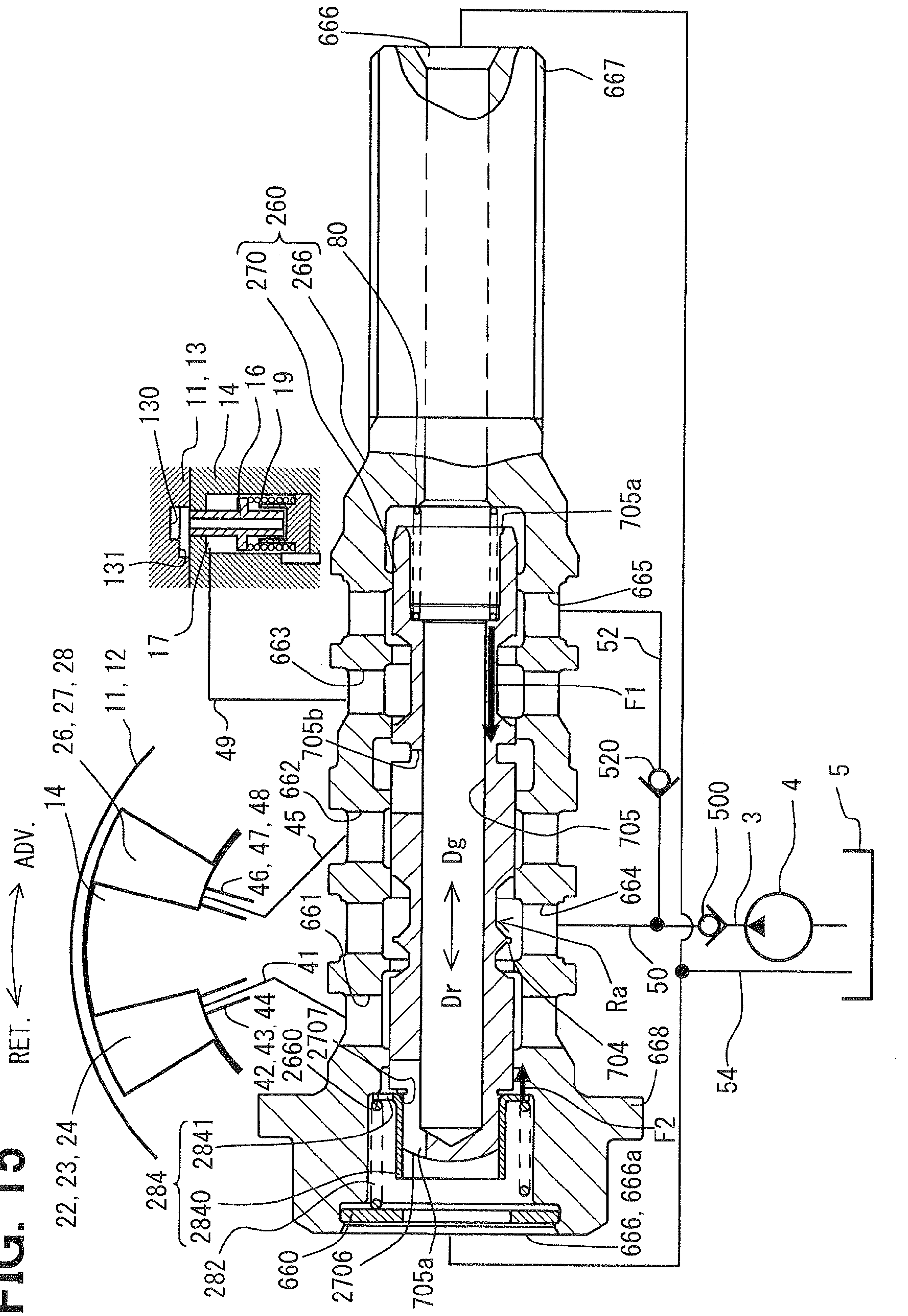
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FIG. 15

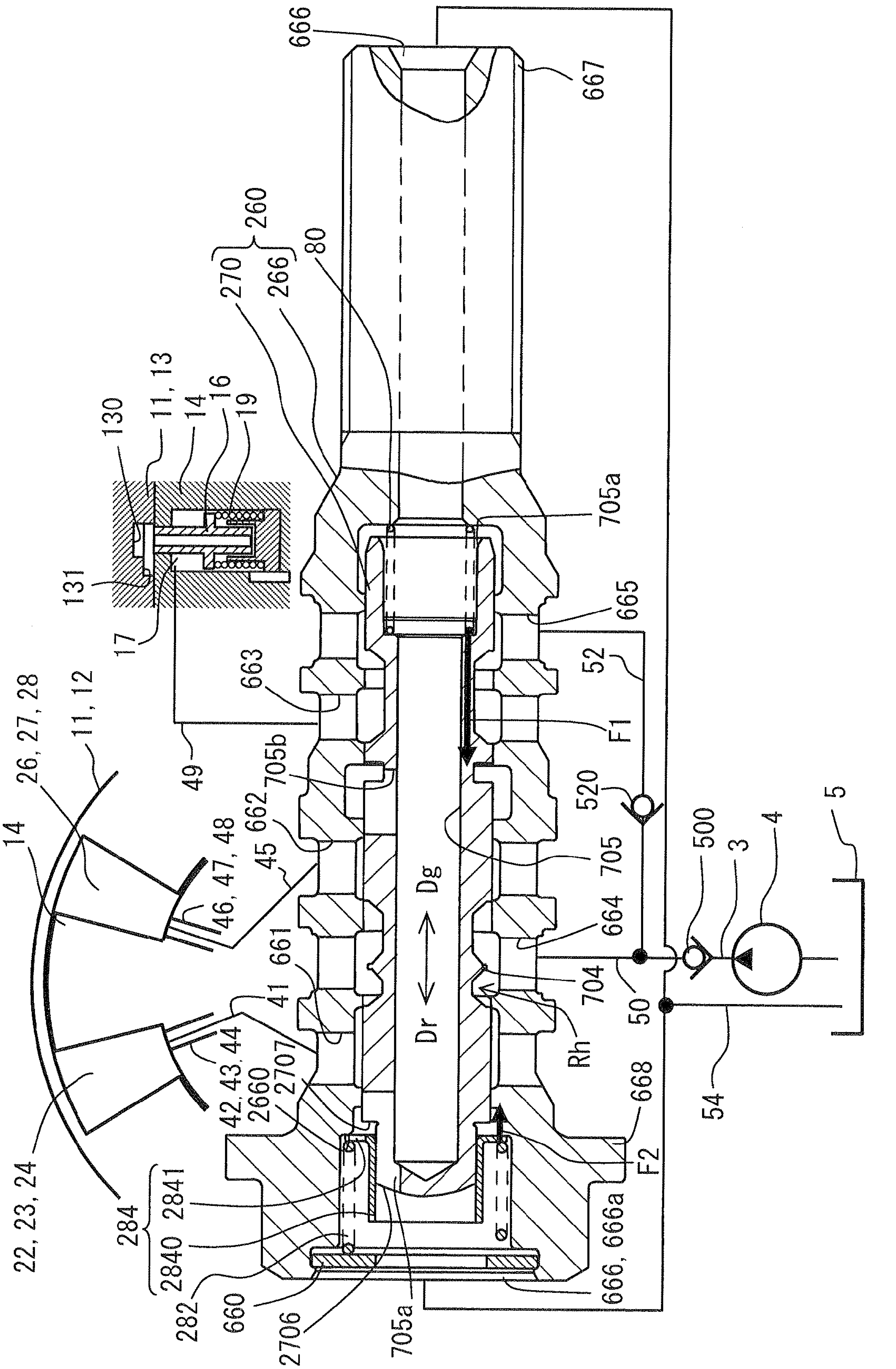
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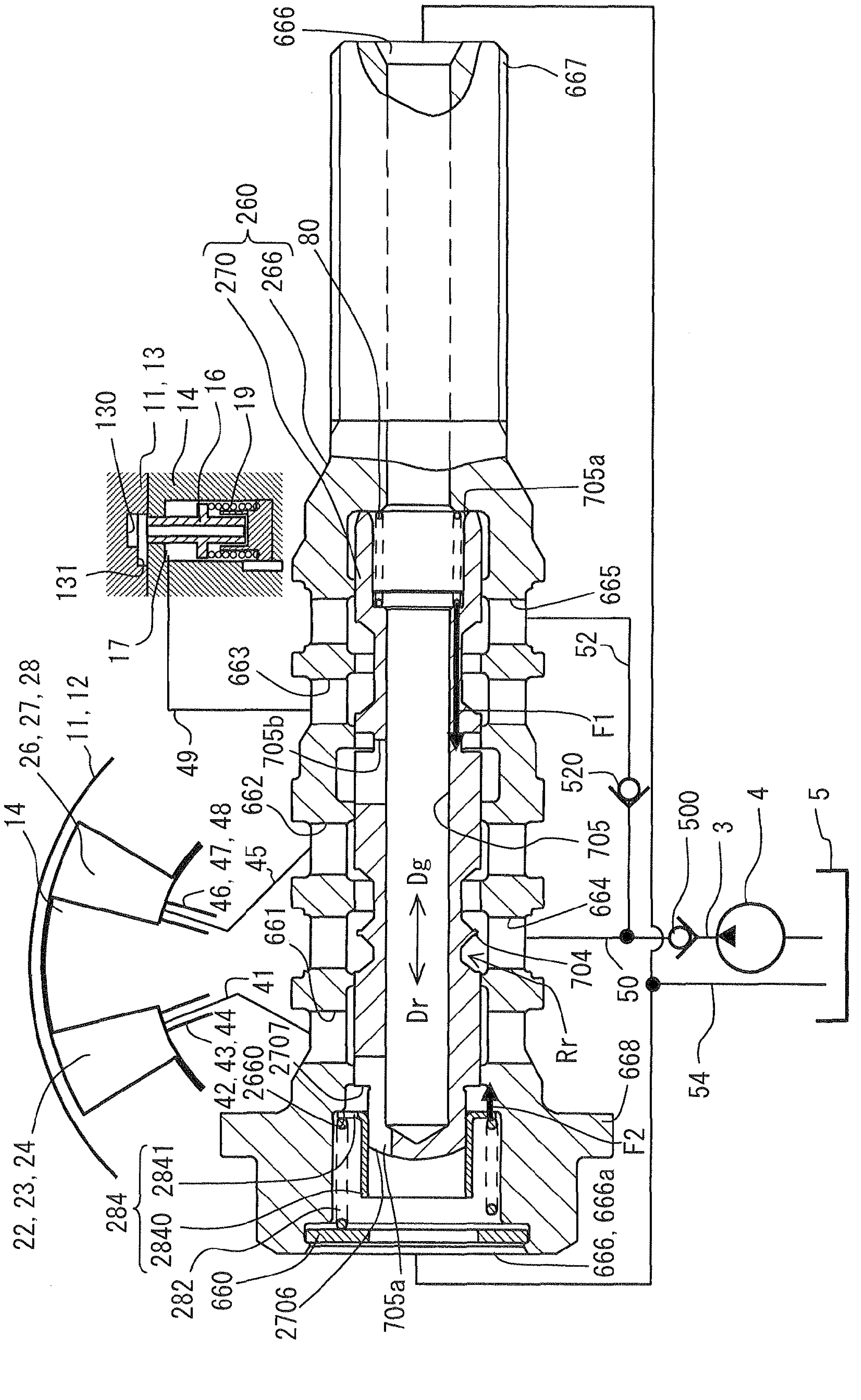
FIG. 16



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Rr
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FIG. 17

FIG. 18A

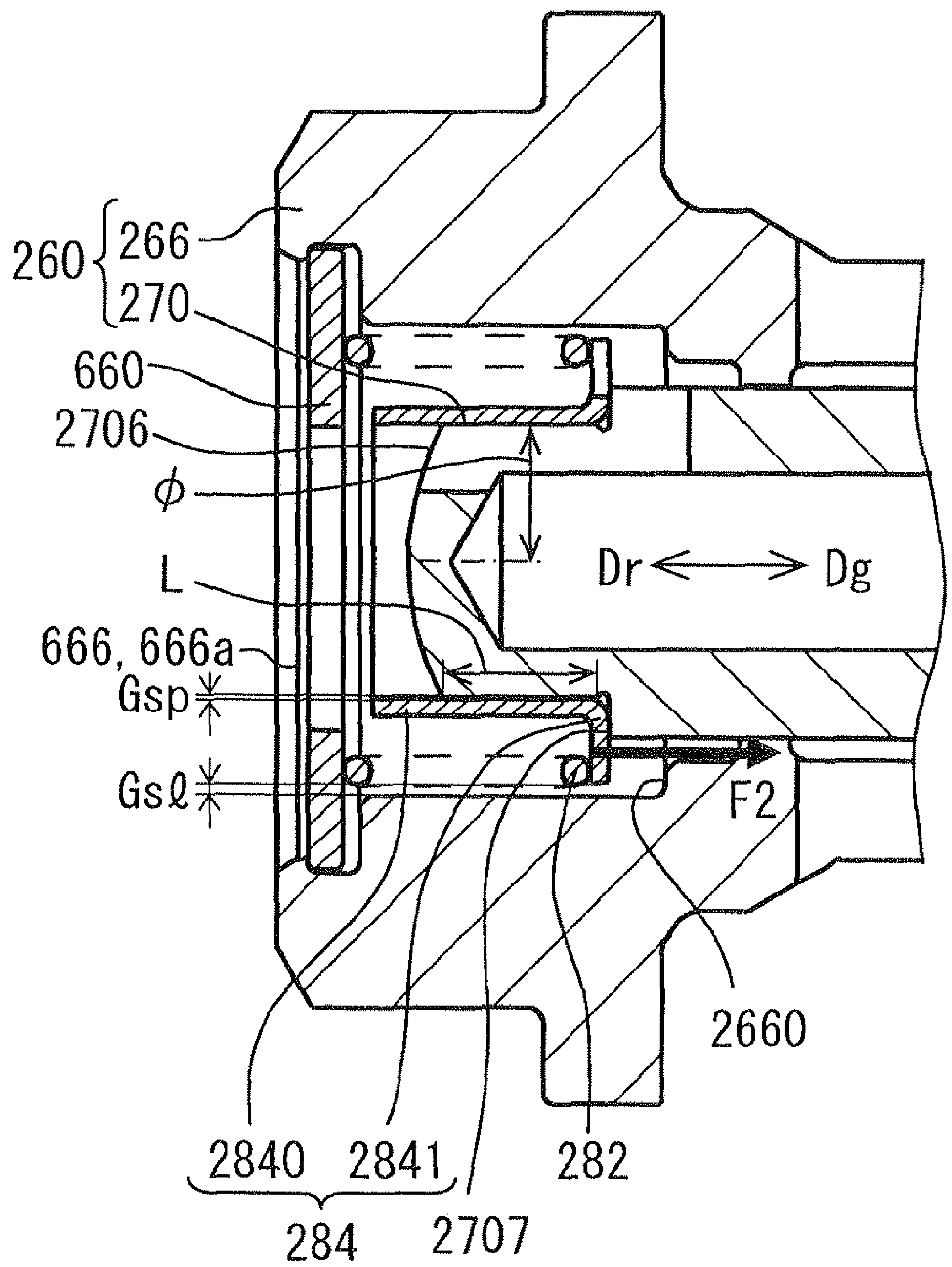
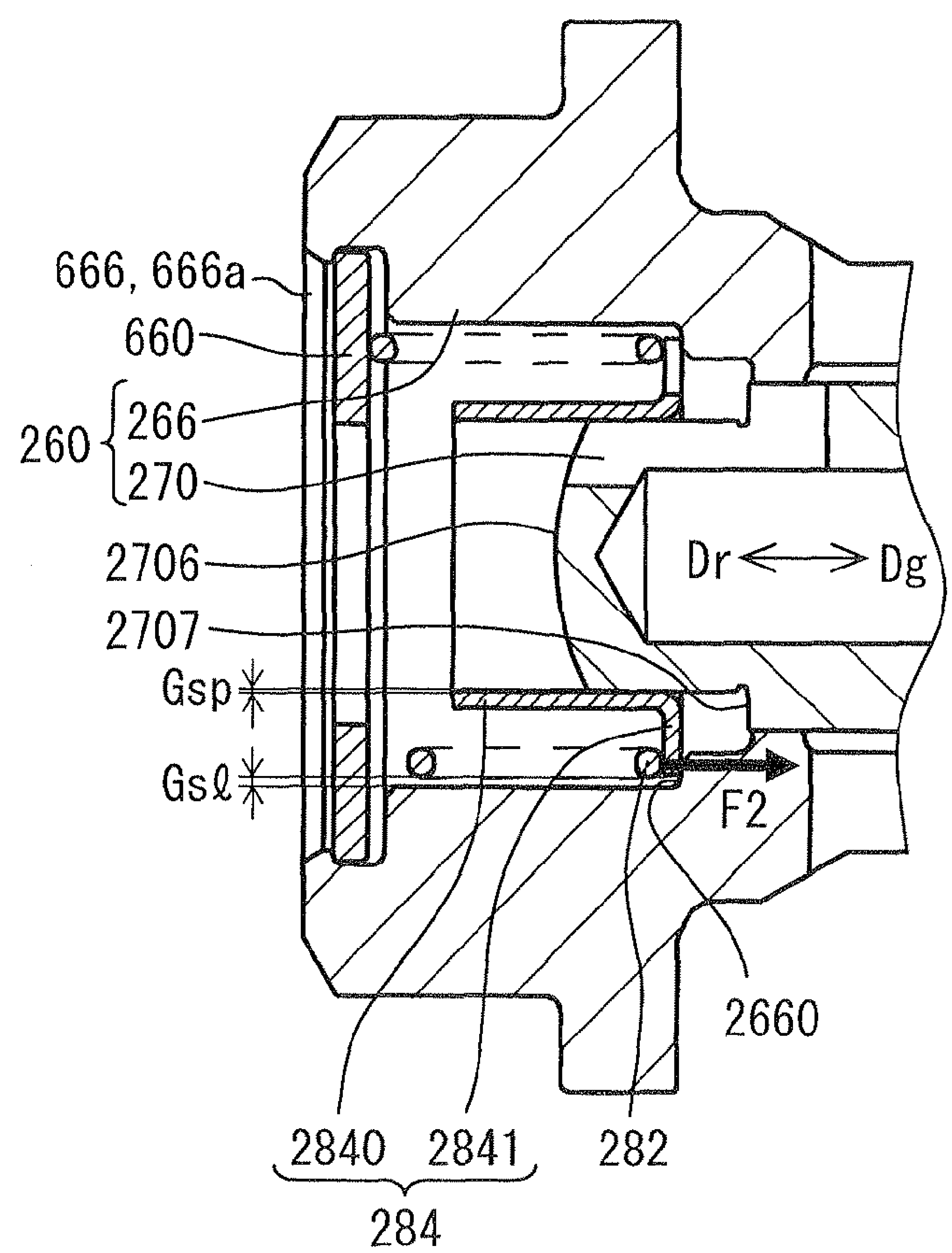


FIG. 18B



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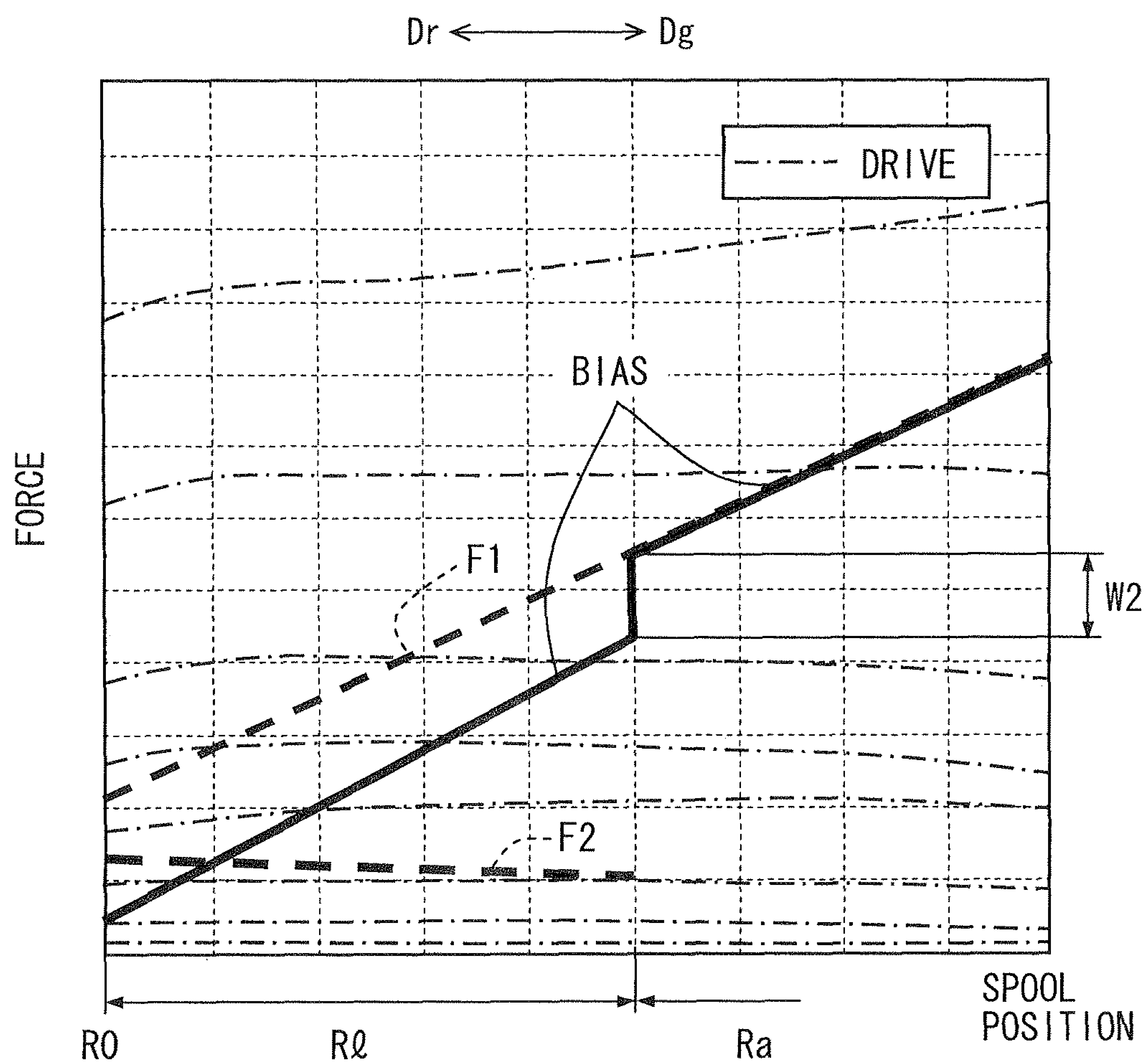


FIG. 20A

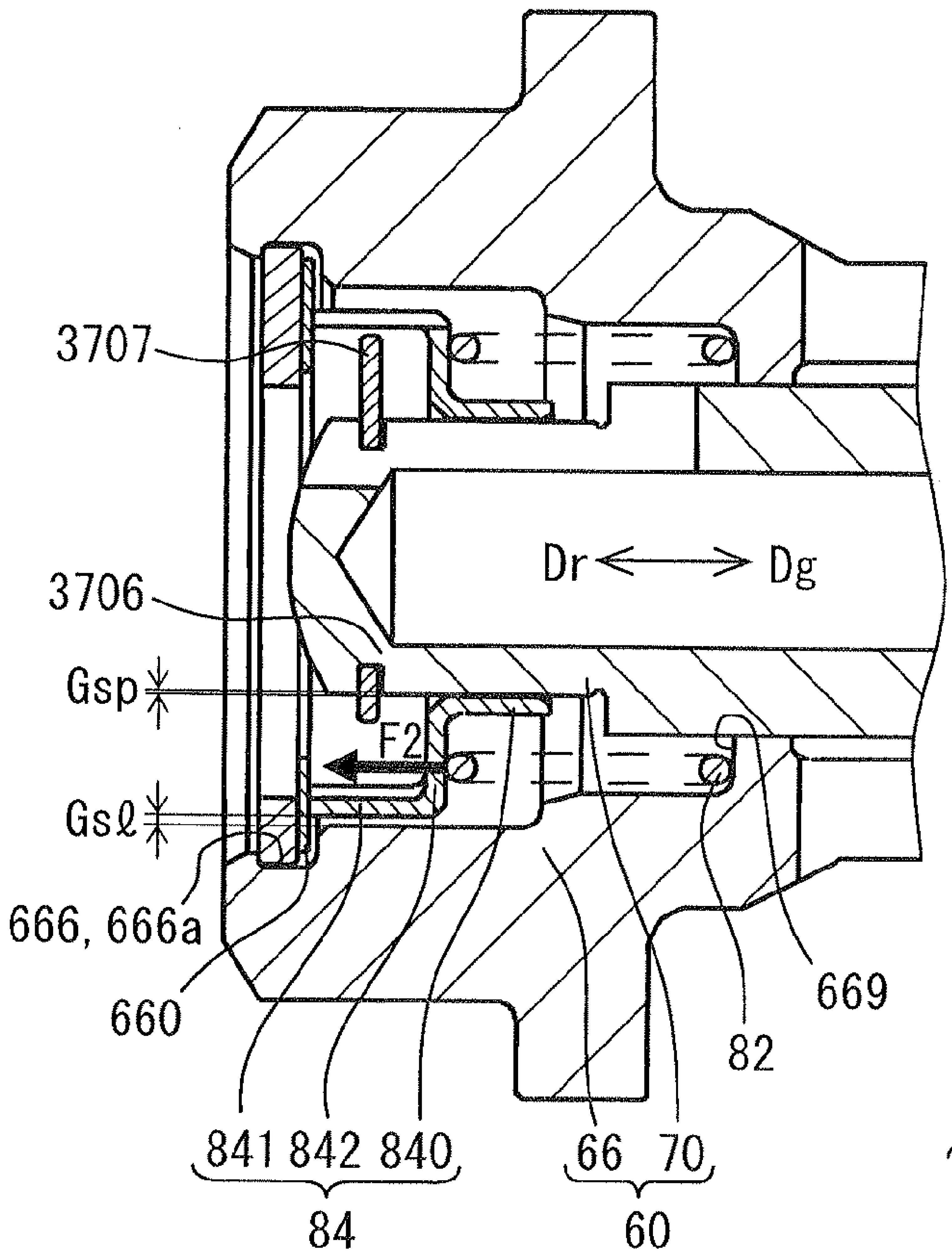


FIG. 20B

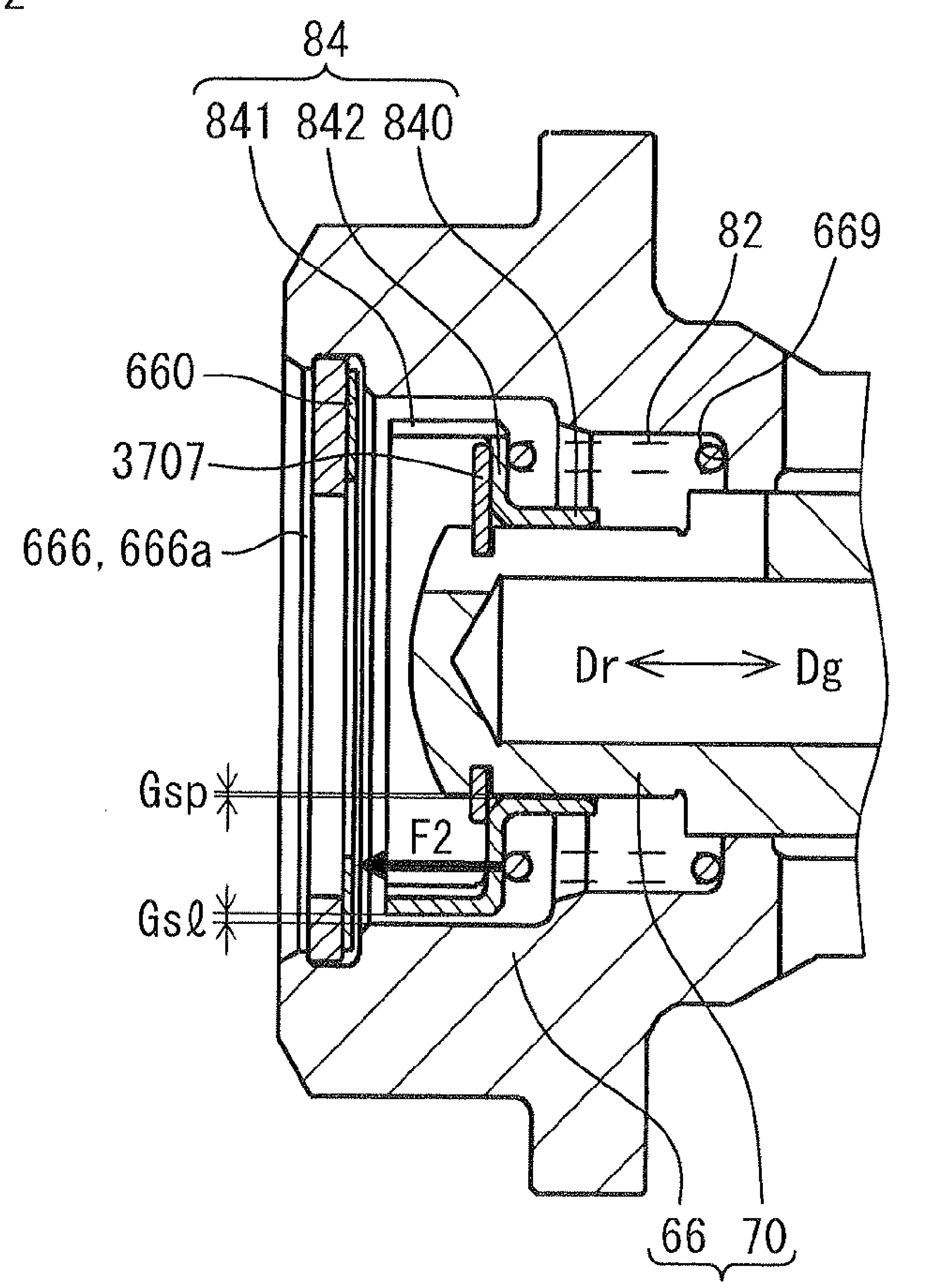
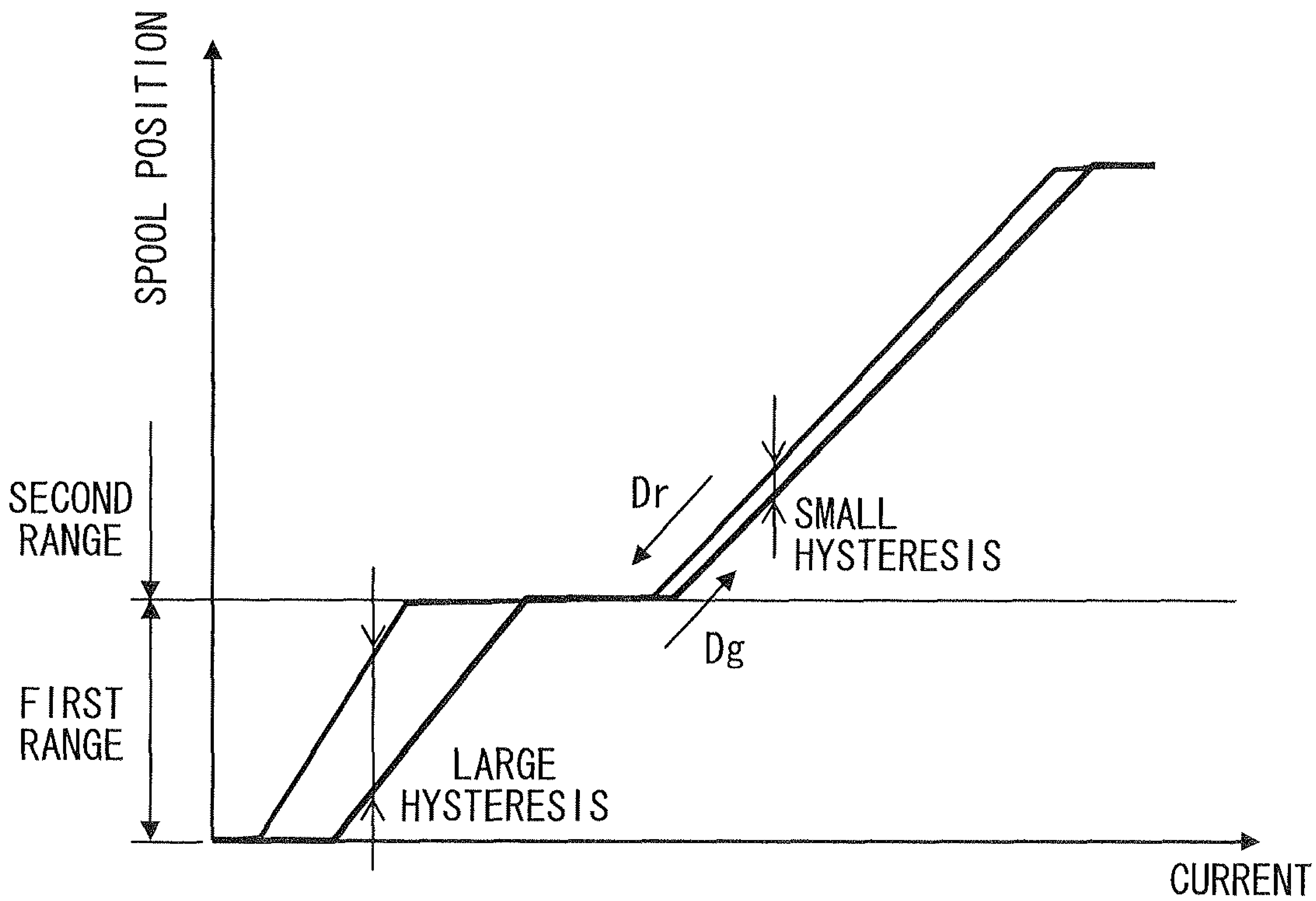


FIG. 21


SPOOL POSITION
SECOND RANGE
FIRST RANGE
Dr
SMALL HYSTERESIS
Dg
LARGE HYSTERESIS
CURRENT

VARIABLE VALVE TIMING DEVICE

CROSS REFERENCE TO RELATED APPLICATION

This application is based on Japanese Patent Application No. 2011-10097 filed on Jan. 20, 2011, the contents of which are incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to a variable valve timing device for adjusting a valve timing of a valve, which is opened and closed by a camshaft driven by a torque transmitted from a crankshaft of the internal combustion engine.

BACKGROUND OF THE INVENTION

Conventionally, several kinds of variable valve timing devices (VVT) are known in this field. For example, a vane type VVT has a housing and a vane rotor relatively rotatable to the housing. The housing is adapted to be rotated with one of a crankshaft and a cam shaft. The vane rotor is housed in the housing and is adapted to be rotated with the other one of the crankshaft and the cam shaft. JP2010-163942A discloses a device that varies a relative rotational phase of the vane rotor with respect to the housing in an advancing direction or a retarding direction. The device varies a phase difference by controlling fluid flow, e.g., by introducing operational fluid into an advancing chamber or a retarding chamber both defined within the housing by dividing a housing chamber by the vane rotor. The VVT may include a control valve having a sleeve and a spool which is slidably supported and housed in the sleeve in a reciprocal manner. The control valve switches and controls introducing flow and discharging flow to the advancing chamber and the retarding chamber in accordance with an axial position of the spool.

The axial position of the spool is controlled in accordance with a balance between an axial driving force and an axial biasing force. The driving force is generated by a driving source in response to an instruction value. The biasing force urges the spool in an opposite direction to the driving force, and is adjusted by a device which provides bias adjusting means, i.e., bias setting means. The bias adjusting means varies the biasing force in a step like manner at a boundary position between two regions. The regions correspond to a movable range of the spool and are defined adjacent to each other in an axial direction. By generating such a step like characteristic on the biasing force by the bias adjusting means, the control valve demonstrates required performance. For this purpose, the control valve may include a movable member and a pair of resilient members. The movable member and the resilient members may be housed in the sleeve.

In the first region, the movable member engages with the spool with respect to the axial direction, and moves with the spool. On the other hand, in the second region, the movable member abuts and rests on the sleeve with respect to the axial direction, and enables a relative movement of the spool. The first resilient member generates a first restoring force that axially urges the spool in both the first region and the second region. The second resilient member generates a second restoring force that axially urges the movable member in both the first region and the second region. By employing such arrangement, since the spool engaged with the movable member by the second restoring force is urged in the axial direction in the first region, a summed force of the second restoring force and the first restoring force acts as a biasing force

against the driving force. On the other hand, in the second region, since a movable member is abut on the sleeve and an urging of the spool by the second restoring force is restricted, only the first restoring force acts as the biasing force against the driving force. Accordingly, the urging force may be changed in a step like manner. This is caused by switching acting force at a boundary position between the first and the second region. The acting force is switched between the summed force of the second restoring force and the first restoring force, and a single force of the first restoring force.

SUMMARY OF THE INVENTION

According to the bias adjusting means disclosed in 3P2010-163942A, the cylindrical movable member is supported from a radial outside by the sleeve, and is kept apart from the spool in a radial outside direction. Therefore, in the second region where the movable member rests on the sleeve, since the spool can move relative to the movable member without contacting the movable member in a radial direction, the spool receives only a small movement resistance. As shown in FIG. **21**, which shows a relationship between a spool position and the instruction value to the driving source, in the second region, there may be a small amount of hysteresis between a movement in an axial forward direction Dg and a movement in an axial reverse direction Dr. Contrary, in the first region where the movable member and the spool are axially engaged to move together, the spool receives a sliding resistance which the movable member generates by coming in contact with the sleeve in the radial direction and sliding on the sleeve. At this movement, the movable member moves while receiving the second restoring force from the second resilient member. Therefore, if an acting direction of the second restoring force inclines to the axial direction of the sleeve, the movable member may receive a side force in the radial direction and be easily pushed onto the sleeve located on the radial outside. Such force pushing the movable member onto the sleeve may be generated therebetween and increases the sliding resistance which increases a movement resistance of the spool. As a result, in the first region, the sliding resistance may act on the spool in both moving directions. As shown in FIG. **21**, in the first region, there may be a large amount of hysteresis between a movement in an axial forward direction Dg and a movement in an axial reverse direction Dr. As a result, the large hysteresis adversely affects the response characteristic of the control valve. In another aspect, the sliding resistance between the movable member and the sleeve may be changed irregularly as the spool moves. This causes the spool to move intermittently. In other words, a stick-slip phenomenon on the spool movement may be easily occurred. As a result, the irregularly changing sliding resistance adversely affects the response characteristic of the control valve.

It is an object of the present invention to provide a variable valve timing device having a control valve with a stable response characteristic.

It is another object of the present invention to provide a variable valve timing device having a control valve which can suppress a variation in the response characteristic.

According to the present invention, a variable valve timing device (VVT) is provided. The VVT adjusts a valve timing of a valve being opened/closed by a camshaft which is driven by a torque transmitted from a crankshaft of an internal combustion engine. The VVT comprises a housing defining a hydraulic chamber therein. The VVT comprises a vane rotor disposed to define an advancing chamber and a retarding chamber by dividing the hydraulic chamber in a rotational direction, the vane rotor being rotatable to change a rotational phase relative to the housing in response to hydraulic fluid introduced into one of the advancing chamber and the retarding chamber. The VVT comprises a control valve having a sleeve and a spool disposed in the sleeve in a reciprocally movable manner, the control valve being adapted to control in-flow and out-flow of the hydraulic fluid with respect to both the advancing chamber and the retarding chamber by adjusting a spool position in an axial direction. The WT comprises a driving source which changes the spool position by generating a driving force of the spool in response to an instruction value. The VVT comprises a biasing device which generates and adjusts a biasing force biasing the spool against the driving force. The control valve provides a first region and a second region arranged along the axial direction in a region where the spool is movable. The biasing device includes a movable member which is capable of being engaged with the spool in the first region to move together with the spool, and is capable of resting on the sleeve in the second region to enable the spool to move relative to the movable member. The biasing device includes a first resilient member which generates a first restoring force for pushing the spool in the axial direction when the spool is in both the first region and the second region. The biasing device includes a second resilient member which generates a second restoring force for pushing the movable member in the axial direction when the spool is in both the first region and the second region. The movable member engages with the spool in the first region to enable the second restoring force to act on the spool. The movable member rests on the sleeve in the second region to disable the second restoring force to act on the spool. The movable member is supported by the spool in a manner that the movable member is apart from the sleeve in a radial direction.

Accordingly, the biasing force may be changed in a step like manner. This is caused by switching acting force at a boundary position between the first and the second region. The acting force is switched between the summed force of the second restoring force and the first restoring force, and a single force of the first restoring force. Therefore, it is possible to provide required characteristics in the first and second regions respectively.

The movable member is apart from the sleeve in a radial direction. Therefore, the spool can move with a small resistance in the first region in which the spool and the movable member are engaged. As a result, it is possible to reduce a hysteresis between a forward movement and a reverse movement. In the second region, the spool may move in a sliding manner on the movable member that rests on the sleeve. However, the movable member can be held stable on the sleeve. Therefore, it is possible to reduce a side force that could push the movable member onto the spool. As a result, it is possible to reduce sliding resistance acting on the spool in the second region, and to reduce a hysteresis between a forward movement and a reverse movement. In addition, since a fluctuation of friction between the spool and the movable member is reduced to a sufficiently low level, it is possible to suppress a stick-slip in the second region. As a result, it is possible to provide the variable valve timing device having the control valve with a stable response characteristic.

BRIEF DESCRIPTION OF THE DRAWINGS

Additional objects and advantages of the present invention will be more readily apparent from the following detailed description of preferred embodiments when taken together with the accompanying drawings. In which:

FIG. **1** is a cross sectional view, on a I-I cross section in FIG. **2**, of a variable valve timing device according to a first embodiment of the present invention;

FIG. **2** is a cross sectional view showing a II-II cross section in FIG. **1**;

FIG. **3** is a characteristic diagram for explaining torque acting on the variable valve timing device in FIG. **1**;

FIG. **4** is a cross sectional view showing a control valve in the variable valve timing device in FIG. **1**;

FIG. **5** is a cross sectional view showing one operational position of the control valve in FIG. **4**;

FIG. **6** is a cross sectional view showing one operational position of the control valve in FIG. **4**;

FIG. **7** is a cross sectional view showing one operational position of the control valve in FIG. **4**;

FIG. **8** is a cross sectional view showing one operational position of the control valve in FIG. **4**;

FIG. **9**A is a cross sectional view showing one operational position of the control valve in FIG. **4**;

FIG. **9**B is a cross sectional view showing one operational position of the control valve in FIG. **4**;

FIG. **10**A is a characteristics diagram of the control valve in FIG. **4**;

FIG. **10**B is a characteristics diagram of the control valve in FIG. **4**;

FIG. **11** is a characteristics diagram of the control valve in FIG. **4**;

FIG. **12** is a characteristics diagram of the control valve in FIG. **4**;

FIG. **13** is a cross sectional view of a control valve for a variable valve timing device according to a second embodiment of the present invention;

FIG. **14** is a cross sectional view showing one operational position of the control valve in FIG. **13**;

FIG. **15** is a cross sectional view showing one operational position of the control valve in FIG. **13**;

FIG. **16** is a cross sectional view showing one operational position of the control valve in FIG. **13**;

FIG. **17** is a cross sectional view showing one operational position of the control valve in FIG. **13**;

FIG. **18**A is a cross sectional view showing one operational position of the control valve in FIG. **13**;

FIG. **18**B is a cross sectional view showing one operational position of the control valve in FIG. **13**;

FIG. **19** is a characteristics diagram of the control valve in FIG. **13**;

FIG. **20**A is a cross sectional view showing a modified embodiment of the control valve;

FIG. **20**B is a cross sectional view showing a modified embodiment of the control valve; and

FIG. **21** is a characteristics diagram of a prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereafter, a plurality of embodiments of the present invention are described. In the following description for embodiments, repetitive description may be omitted by using the same reference symbols for indicating the same or corresponding parts and components. In a case that only a part of structure of embodiment is described, the preceding description for the corresponding parts in the preceding embodiments may be referenced to understand such part that is not described in detail. It is possible to combine any components in different embodiments selectively, if such combination is clearly described. In addition, even if such combinations are not clearly described, it is possible to combine any components in different embodiments selectively unless no trouble arise in such combinations.

(First Embodiment)

FIG. **1** shows a first embodiment in which a variable valve timing device **1** is applied to an internal combustion engine for a vehicle. The variable valve timing device **1** is a fluid driven type which uses oil as hydraulic fluid, and adjusts valve timing of an inlet valve assumed as a valve.

(Basic Components)

First, the basic components of the variable valve timing device **1** are explained. As shown in FIGS. **1** and **2**, the variable valve timing device **1** includes a rotary-mechanism part **10** and a control part **40**. The rotary-mechanism part **10** is disposed in a transmission system which transmits an engine torque outputted from a crankshaft (not shown) to the cam shaft **2** in the internal combustion engine. The control part **40** controls in-flow and out-flow of the hydraulic oil for driving the rotary-mechanism part **10**.

(Rotary Mechanism Part)

In the rotary-mechanism part **10**, the housing **11** is formed by placing and tightening a rear plate **13** and a front plate **15** on both axial end of the shoe casing **12**. The housing **11** defines a hydraulic chamber therein. The housing **11** is adapted to rotate synchronously with the crankshaft. A shoe casing **12**, i.e., a housing, includes a housing body **120** provided as a cylindrical-main part, a plurality of shoes **121**, **122**, **123** provided as partition portions, and a sprocket **124**. The shoes **121**, **122**, **123** are circumferentially arranged one after another at predetermined intervals on an inner surface of the housing body **120** and radially inwardly projects therefrom. Chambers **20** are formed between circumferentially adjacent pair of the shoes **121**, **122**, **123**, respectively. The sprocket **124** is connected with the crankshaft via a timing chain (not shown). During rotation of the internal combustion engine, since the engine torque is transmitted from the crankshaft to the sprocket **124** via the connection, the housing **11** is interlocked with the crankshaft and rotates in the predetermined direction (the clockwise direction in FIG. **2**.)

A vane rotor **14** is disposed in the hydraulic chamber defined in the housing **11**. The vane rotor **14** has a rotational axis that is supported coaxial with a rotational axis of the housing **11**. The vane rotor **14** and the housing **11** are arranged on the same axis. The vane rotor **14** is arranged in the housing **11** so that both side surfaces of the vane rotor **14** are slidably in contact with the rear plate **13** and the front plate **15**. The vane rotor is adapted to rotate synchronously with the cam shaft **2**. The vane rotor **14** includes a shaft **140** provided as a cylindrical rotatable part, and a plurality of vanes **141**, **142**, **143** provided as partition portions. The shaft **140** is secured on the cam shaft **2** in a coaxial manner. Thereby, the vane rotor **14** is rotatable with the cam shaft **2** in a direction, i.e., clockwise direction shown in FIG. **2**, in which the housing **11** is also rotatable. The vane rotor **14** is relatively rotatable to the housing **11** within a predetermined relative rotatable range. In the present embodiment, the shaft **140** includes a shaft body **140***a*, a boss **140***b* on one end of the shaft body **140***a* and a bush **140***c* on the other end of the shaft body **140***a*. The boss **140***b* axially penetrates the rear plate **13** and is connected to the camshaft **12**. The bush **140***c* axially penetrates the front plate **15** and provides an inner cavity which opens toward outside of the housing **11**.

The vanes **141**, **142**, **143** are arranged on the shaft body **140***a* and protrude in a radial outside direction from the shaft body **140***a*. The vanes **141**, **142**, **143** protrude from outer portions which are distanced predetermined intervals each other. Each of the vanes **141**, **142**, **143** is placed in a corresponding one of the chambers **20**. The vane rotor **14** is rotatable to change a rotational phase relative to the housing **11** in response to hydraulic fluid introduced into one of the advancing chambers **22**, **23**, **24** and the retarding chambers **26**, **27**, **28**. The vane rotor **14** is disposed to define advancing chambers **22**, **23**, **24** and retarding chambers **26**, **27**, **28** by dividing the hydraulic chamber **20** in a rotational direction. In detail, each of the vanes **141**, **142**, **143** divides the corresponding chamber **20** in the rotational direction. As a result, the vanes **141**, **142**, **143** define the advancing chambers **22**, **23**, **24** and retarding chambers **26**, **27**, **28** which introduce or discharge the hydraulic fluid. An advancing chamber **22** is defined between the shoe **121** and the vane **141**. An advancing chamber **23** is defined between the shoe **122** and the vane **142**. An advancing chamber **24** is defined between the shoe **123** and the vane **143**. A pair of the advancing chamber and the retarding chamber is defined on both rotational sides of the vane. A retarding chamber **26** is formed between the shoe **122** and the vane **141**. A retarding chamber **27** is formed between the shoe **123** and the vane **142**. A retarding chamber **28** is defined between the shoe **121** and the vane **143**.

The vane **141** accommodates a lock member **16** which can be engaged with a lock hole **130** formed on the rear plate **13** to lock rotational phase of the vane rotor **14** to the housing **11**. In order to drive the lock member **16**, the vane **141** defines a lock release chamber **17** in which the hydraulic oil is introduced to unlock the phase by disengaging the lock member **16** from the lock hole **130**.

The rotary-mechanism **10** varies the valve timing by varying the phase difference between the housing **11** and the vane rotor **14** when the lock pin **32** is disengaged from the lock hole **31**. The rotary-mechanism **10** varies the phase in an advancing direction, and advances the valve timing by introducing the hydraulic oil into the advancing chambers **22**, **23**, **24** and discharging the hydraulic oil from the retarding chambers **26**, **27**, **28**. The rotary-mechanism **10** varies the phase in a retarding direction, and retards the valve timing by discharging the hydraulic oil from the advancing chambers **22**, **23**, **24** and introducing the hydraulic oil into the retarding chambers **26**, **27**, **28**.

In this embodiment, a regulated phase region is defined as a region that is preferable for starting the internal combustion engine. The regulated phase region is set a part of a variable range which can be realized by the rotary-mechanism part **10**. The regulated phase region extends from a predetermined middle phase between the most retarded phase and the most advanced phase to the most advanced phase. In addition, a lock phase is defined within the regulated phase region. In the lock phase the rotary-mechanism part **10** is locked by the lock member **16**. The lock phase is set as a middle phase in the regulated phase region, and is defined as an optimal phase for starting the internal combustion engine. According to such arrangement, it is possible to ease starting up of the internal combustion engine by suppressing excessive decrease of an intake air amount caused by a delayed closure of the intake valve at the start up of the internal combustion engine.

(Control Part)

A main-advance passage **41** is formed along an inner periphery of the shaft **140**. Branch advance passages **42**, **43**, **44** penetrate the shaft **140**. The branch advance passages **42**, **43**, **44** are fluidly communicated with corresponding advancing chambers **22**, **23**, **24** respectively and are also communicated with the main-advance passage **45** commonly. A main-retard passage **45** is formed by a groove opening on an inner periphery of the shaft **140**. Branch retard passages **46**, **47**, **48** penetrate the shaft **140**. The branch retard passages **46**, **47**, **48** are fluidly communicated with corresponding retarding chambers **26**, **27**, **28** respectively and also communicated with the main-retard passage **45** commonly. A lock release passage **49** penetrates the shaft **140** and is fluidly communicate with the lock release chamber **17**.

A main-supply passage **50** penetrates the shaft **140** and is fluidly communicated with a pump **4** through a feed passage **3** formed in the cam shaft **2**. The pump **4** is a supply source of the hydraulic oil. The pump **4** is a mechanical pump driven by the internal combustion engine through the crank shaft. While the engine is operated, the pump **4** pumps up the hydraulic oil from a drain pan **5** and continuously discharges the hydraulic oil to the feed passage **3**. The feed passage **3** always communicates with a discharge port of the pump **4** without respect to the rotation of the cam shaft **2**. Thus, while the engine is operated, the hydraulic oil discharged from the pump **4** is continuously supplied to the main-supply passage **50**.

A sub-supply passage **52** penetrates the shaft **140**, and is branched from the main-supply passage **50**. The sub-supply passage **52** receives the hydraulic oil supplied from the pump **4** through the main-supply passage **50**. As shown in FIG. **4**, a main-check valve, e.g., lead valve, **500** is disposed in the main-supply passage **50** between a branch portion to the sub-supply passage **52** and the pump **4**. A sub-check valve **520** is disposed in the sub-supply passage **52**. The main-check valve **500** prevents the hydraulic oil from flowing backwards to the pump **4** side in the main-supply passage **50**. The sub-check valve **520** prevents the hydraulic oil from flowing backwards to the main-supply passage **50** side in the sub-supply passage **52**.

A drain recovering passage **54** is disposed on outside components from the rotary-mechanism part **10** and the cam shaft **2**. The drain recovering passage **54** is formed to discharge the hydraulic oil to the drain pan **5**, and is opened to atmospheric air with the drain pan **5** as a drain recovering components.

The variable valve timing device includes a control valve **60**. The control valve **60** has a sleeve **66** and a spool **70** disposed in the sleeve **66** in a reciprocally movable manner. The control valve **60** is adapted to control in-flow and out-flow of the hydraulic fluid with respect to both the advancing chambers and the retarding chambers by adjusting a spool position in an axial direction to switch communication among ports.

The control valve **60** is a spool type valve in which the spool **70** disposed in the sleeve **66** is driven in a reciprocal manner in an axial direction. The spool **70** is driven to change a spool position by using restoring forces obtained by the resilient members **80** and **82** and driving force generated by the driving source **90** in response to an electric power supplied to the driving source **90**. The control valve **60** provides an advancing port **661**, a retarding port **662**, a lock release port **663**, a main-supply port **664**, a sub-supply port **665**, and a drain port **666**. The advancing port **661** is formed to communicate with an advance-main passage **41**. The retarding port **662** is formed to communicate with a retard-main passage **45**. The lock release port **663** is formed to communicate with a lock release passage **49**. The main-supply port **664** is formed to communicate with a main-supply passage **50**. The sub-supply port **665** is formed to communicate with a sub-supply passage **52**. A pair of drain ports **666** is formed to communicate with a drain recovering passage **54**. The control valve **60** changes communicating state among the ports **661**, **662**, **663**, **664**, **665**, **666** according to a spool position that is variable by driving the spool **70**.

The control circuit **96** may be provided by an electric circuit which includes main components such as a micro computer. The control circuit **96** is electrically connected with the driving source **90** and other electrical components for the internal combustion engine. The control circuit **96** performs controls for the internal combustion engine. The control circuit **96** at least performs a current control for the driving source **90** based on computer program stored in an internal memory.

(Torque on Vane Rotor)

Next, a fluctuation torque which acts on the vane rotor **14** from the cam shaft **2** is explained. During rotation of the internal combustion engine, the cam shaft **2** drives the valve, e.g., the intake valve, and receives the fluctuation torque caused by a spring reaction force from a spring on the valve, etc. The fluctuation torque also acts on the vane rotor **14** of the rotary-mechanism part **10** through the cam shaft **2**. As shown in FIG. **3**, the fluctuation torque changes in an alternating manner between a negative torque acting in the advancing direction to the housing **11** and the positive torque acting in the retarding direction to the housing **11**. In this embodiment, due to causes such as a friction between the cam shaft **2** and bearings, a positive peak torque "T+" is larger than a negative peak torque "T−", and an average torque "Tave" is shifted to the positive torque side. Therefore, the vane rotor **14** is biased to the retarding direction to the housing **11** by the fluctuation torque transmitted from the cam shaft **2** during rotation of the internal combustion engine.

(Vane Rotor Components)

Next, components which drive the vane rotor **14** toward a lock phase are explained. Referring to FIG. **1**, in the rotary-mechanism part **10**, a first engage pin **150** is disposed in a front plate **15** of the housing **11**. The first engage pin **150** is formed in a columnar shape and is protruded from the front plate **15** toward an outside of the housing **11**. The first engage pin **150** is disposed in parallel to a rotation center line "O" of the rotary-mechanism part **10** and on an eccentric location from the rotation center line "O". An arm portion **140*d*** and a second engage pin **140*e*** are disposed on a bush **140*c*** which is formed on the shaft **140** and protrudes from the front plate **15** toward an outside of the housing **11**. The arm portion **140*d*** is formed in a substantially plate shape which extends in parallel to the front plate **15**. The second engage pin **140*e*** is formed in a columnar shape and is protruded from the arm portion **140*d*** to the front plate **15**. The second engage pin **140*e*** is disposed in parallel to the rotation center line "O" and on an eccentric location from the rotation center line "O". The first engage pin **150** is disposed to provide a first eccentric distance from the rotation center line "O". The second engage pin **140*e*** is disposed to provide a second eccentric distance from the rotation center line "O". The pins **150** and **140*e*** are arranged to make the first and second eccentric distance substantially equal. The second engage pin **140*e*** is disposed to be placed out of a rotation locus of the first engage pin **150** in the axial direction of the rotary-mechanism part **10**.

An assist spring **18** made of metal is arranged around the bush **140*c***. The assist spring **18** is a spiral spring which is manufactured by winding a material piece on a substantially flat plane. The assist spring **18** is disposed between the front plate **15** and the arm portion **140*d*** in a manner that a winding center is placed on the rotation center line "O". An inner end of the assist spring **18** forms a wound part **180** by winding itself on an outer periphery of the bush **140*c***. An outer end of the assist spring **18** forms an engage part **181** by bending itself in a U shaped portion. The engage part **181** is formed and placed to be able to engage with either one of the first engage pin **150** and the second engage pin **140*e*** according to a rotation phase.

When the rotation phase is adjusted in a range in a retard side from the lock phase, the engage part **181** of the assist spring **18** engages with the first engage pin **150** on the housing

11. At this time, the second engage pin **140**e on the vane rotor **14** is apart from the engage part **181**. Therefore, the vane rotor **14** is pushed toward the lock phase in an advancing direction by receiving a restoring force generated by the assist spring **18**. In this embodiment, the restoring force of the assist spring **18** biasing the vane rotor **14** in the advancing direction is set larger than an average value of a fluctuation torque that is shifted to the retarding direction.

On the other hand, when the rotation phase is adjusted in a range in an advance side from the lock phase, the engage part **181** of the assist spring **18** engages with the second engage pin **140**e on the vane rotor **14**. At this time, the first engage pin **150** on the housing **11** is apart from the engage part **181**. Therefore, the biasing on the vane rotor **14** by the assist spring **18** is restricted.

(Lock Components)

Next, components which lock the rotation phase are explained. As shown in FIGS. **1**, **2**, and **4**, the rear plate **13** has a regulated hole **131** and a lock hole **130**. The regulated hole **131** may be referred to as a restriction hole **131** to restrict a variable range. The regulated hole **131** is formed in a groove shape with a closed bottom and is extended along the rotating direction and is terminated on both ends. The lock hole **130** is formed in a circular hole with a closed bottom and opens on the bottom of the regulated hole **131** at an advanced side end.

In the vane rotor **14**, the vane **141** has a receiving hole **141**a in which a cylindrical lock member **16** is accommodated in parallel to a rotational center line "O" of the rotary-mechanism part **10**. The receiving hole **141**a is placed to face the regulated hole **131** in the axial direction in the regulated phase region, and to face the lock hole **130** in the axial direction in the lock phase.

A lock spring **19** made of a metal compression coil spring is coaxially accommodated in the receiving hole **141**a in a coaxial manner with the lock member **16**. The lock spring **19** is deformed by compressing it by disposing it between a retainer **141**b fixed on the vane **141** and the lock member **16**. Thereby, the lock spring **19** generates a restoring force which pushes and biases the lock member **16** toward a side to the rear plate **13**. The receiving hole **141**a forms a lock release chamber **17** which is located on a side of the lock member **16** opposite to the lock spring **19** to push the lock member **16** against the lock spring **19**. The lock member **16** is movable in the receiving hole **141**a. The lock member **16** moves toward the rear plate **13** when the lock spring **19** prevails pressure acting on the lock member **16** from the hydraulic oil introduced into the lock release chamber **17**. The lock member **16** moves to be apart from the rear plate **13** when pressure of the hydraulic oil exceeds the biasing force of the lock spring **19**.

When the lock member **16** is disengaged from both the regulated hole **131** and the lock hole **130**, the rotary-mechanism **10** can vary the valve timing for maximum range. If hydraulic oil is discharged from the lock release chamber **17**, when the lock member **16** has disengaged from both the regulated hole **131** and the lock hole **130**, the lock member **16** moves toward the rear plate **13** side, and first inserted into the regulated hole **131**. When the lock member **16** is engaged with the regulated hole **131** alone, the rotary-mechanism **10** can vary the valve timing for regulated range that is smaller than the maximum range. Then, if the phase is changed by receiving forces such as a fluctuation torque and a restoring force of the assist spring **18** and reaches to the lock phase, the lock member **16** further moves toward the rear plate **13** and is inserted into the lock hole **130** to be firmly engaged with the lock hole **130**. As a result, since the phase can be locked at the lock phase, it is possible to restrict changing of the valve timing in the lock phase.

When the lock member **16** is engaged with the lock hole **130** through the regulated hole **131**, the rotary-mechanism **10** can not vary the valve timing. If hydraulic oil is introduced into the lock release chamber **17**, when the lock member **16** has engaged with the lock hole **130**, the lock member **16** moves in a direction opposite to the rear plate **13**, and is pulled out from the lock hole **130** and the regulated hole **131**. As a result, since the lock for phase is released, it is possible to change the valve timing freely within the maximum range.

(Detail of Control Valve)

Next, the detailed structure of the control valve **60** is explained. FIG. **1** shows a control valve **60**. Since the cam shaft **2** and the vane rotor **14** are engaged to rotate together, those members provide rotary components **2**, **14**. A sleeve **66** is made of metal in a cylindrical shape, and is disposed inside the rotary components **2**, **14** in a coaxial manner with the rotary components **2**, **14**. The sleeve **66** includes a securing portion **667** and a flange portion **668**. The securing portion **667** is formed on one end of the sleeve **66** and is formed with a male thread which can be screwed on the cam shaft **2**. The flange portion **668** is firmed on the other end of the sleeve **66** and is formed in a circular flange shape. The flange portion **668** and the cam shaft **2** clamps the shaft **140** of the vane rotor **14**. As shown in FIG. **4**, the sleeve **66** provides a plurality of ports for in-flow and out-flow of the hydraulic oil. The sleeve **66** has the following ports in an order from an axial end on the flange portion **668** side to an axial end on the securing portion **667** side: one of the drain port **666**; the advancing port **661**; the main-supply port **664**; the retarding port **662**; the lock release port **663**; the sub-supply port **665**; and the other one of the drain port **666**.

The spool **70** is made of metal and is formed in a cylindrical shape. The spool **70** is coaxially disposed in the sleeve **66** in a manner that the spool **70** is slidingly supported on an inner surface of the sleeve **66** so that the spool **70** is movable in a reciprocal manner in the axial forward direction Dg and the axial reverse direction Dr. The axial forward direction Dg corresponds to a direction in which the spool **70** moves toward the securing portion **667**. The axial reverse direction Dr corresponds to a direction in which the spool **70** moves toward the flange portion **668**. The spool **70** includes a restrictor portion **704** which restricts a flow amount of the hydraulic oil between the advancing port **661** and the main-supply port **664** at a predetermined position. As shown in FIG. **4**, the restrictor portion **704** restricts a flow amount of the hydraulic oil by forming a radial gap between circumferential surfaces. One of circumferential surfaces is provided by an inner surface of the sleeve **66**. The other one of circumferential surface is provided by an outer surface of the restrictor portion **704** which is formed smaller in diameter than the inner surface of the sleeve **66**. Alternatively, although it is not illustrated, the restrictor portion **704** may restrict a flow amount of the hydraulic oil mainly by a length of passage. In this case, the inner surface of the sleeve **66** and the outer surface of the restrictor portion **704** may be formed to slide each other to make the radial gap narrow, but are formed to shorten an axial length of the radial gap.

The spool **70** has a communication passage **705** formed in a cylindrical hole which extends through a radial center in the axial direction. The communication passage **705** provides primary openings **705**a on both axial ends of the spool **70**. Therefore, the communication passage **705** is always fluidly communicated with both the drain ports **666** irrespective of the spool position. Furthermore, the spool **70** has a secondary opening **705**b on an axial middle part of the spool **70**. The opening **705**b is communicated with the communication passage **705**. The opening **705**b is disposed to be communicated with at least one of the retarding port **662** and the lock port **663** according to the axial position of the spool **70**.

FIG. **10**A shows changing characteristics of flow areas between the ports provided on the control valve. When the spool **70** moves to the lock region Rl shown in FIG. **10**A, the advancing port **661** is connected with the main-supply port **664** as shown in FIGS. **4** and **5**. The hydraulic oil supplied from the pump **4** to the passages **3**, **50** is introduced into the advancing chambers **22**, **23**, **24** through the ports **664**, **661** and the passage **41**, **42**, **43**, **44**. At this time, introducing amount of the hydraulic oil to the advancing chambers **22**, **23**, **24** may be restricted by the restrictor portion **704**. When the spool **70** moves to the lock region Rl, the retarding port **662** is connected with the drain ports **666** through the passage **705**. The hydraulic oil in the retarding chambers **26**, **27**, **28** is discharged to the drain pan **5** disposed on a downstream side to the passage **54** through the passages **46**, **47**, **48**, **45** and the ports **662**, **666**. When the spool **70** moves to the lock region Rl, the lock release port **663** is connected with the drain ports **666** through the passage **705**. The hydraulic oil in the lock release chamber **17** is discharged to the drain pan **5** through the passage **49** and the ports **663**, **666**.

The lock region Rl and the advancing region Ra are defined adjacent to each other without any overlap and gap. The advancing region Ra is on the axial forward side to the lock region Rl. When the spool **70** moves to the advancing region Ra shown in FIG. **10**A, the advancing port **661** is connected with the main-supply port **664** as shown in FIG. **6**. The hydraulic oil supplied from the pump **4** to the passages **3**, **50** is introduced into the advancing chambers **22**, **23**, **24** through the ports **664**, **661** and the passage **41**, **42**, **43**, **44**. When the spool **70** moves to the advancing region Ra, the retarding port **662** is connected with the drain ports **666** through the passage **705**. The hydraulic oil in the retarding chambers **26**, **27**, **28** is discharged to the drain pan **5** through the passages **46**, **47**, **48**, **45** and the ports **662**, **666**. When the spool **70** moves to the advancing region Ra, the lock release port **663** is connected with the sub-supply port **665**. The hydraulic oil supplied from the pump **4** to the passages **3**, **50**, **52** is introduced into the lock release chamber **17** through the ports **665**, **663** and the passage **49**.

The holding region Rh and the advancing region Ra are defined adjacent to each other without any overlap and gap. The holding region Rh is on the axial forward direction Dg to the advancing region Ra. When the spool **70** moves to the holding region Rh shown in FIG. **10**A, both the advancing port **661** and the retarding port **662** are disconnected from any other ports as shown in FIG. **7**. The hydraulic oil is kept in the advancing chambers **22**, **23**, **24** and the retarding chambers **26**, **27**, **28**. When the spool **70** moves to the holding region Rh, the lock release port **663** is connected with the sub-supply port **665**. The hydraulic oil supplied from the pump **4** to the passages **3**, **50**, **52** is introduced into the lock release chamber **17** through the ports **665**, **663** and the passage **49**.

The holding region Rh and the retarding region Rr are defined adjacent to each other without any overlap and gap. The retarding region Rr is on the axial forward direction Dg to the holding region Rh. When the spool **70** moves to the retarding region Rr shown in FIG. **10**A, the advancing port **661** is connected with the drain ports **666** through the passage **705** as shown in FIG. **8**. The hydraulic oil in the advancing chambers **22**, **23**, **24** is discharged to the drain pan **5** through the passages **42**, **43**, **44**, **41** and the ports **661**, **666**. When the spool **70** moves to the retarding region Rr, the retarding port **662** is connected with the main-supply port **664**. The hydraulic oil supplied from the pump **4** to the passages **3**, **50** is introduced into the retarding chambers **26**, **27**, **28** through the ports **664**, **662** and the passage **45**, **46**, **47**, **48**. When the spool **70** moves to the retarding region Rr, the lock release port **663** is connected with the sub-supply port **665**. The hydraulic oil supplied from the pump **4** to the passages **3**, **50**, **52** is introduced into the lock release chamber **17** through the ports **665**, **663** and the passage **49**.

(Driving Mechanism)

Next, components for driving the control valve **60** are explained. The control valve **60** provides a first region and a second region arranged along the axial direction in a region where the spool **70** is movable. As shown in FIG. **1**, in order to drive the control valve **60**, the control part **40** includes components such as a biasing device in addition to the driving source **90**. The biasing device generates and adjusts a biasing force biasing the spool **70** against the driving force. The biasing device includes a resilient member **80**, a resilient member **82**, and a movable member **84**.

The driving source **90** is provided by an electro-magnetic solenoid, and is secured on a mounting part on the internal combustion engine, e.g., a chain cover. The driving source **90** has a drive shaft **91** formed in a columnar shape by metal. The drive shaft **91** is disposed on a side of the spool **70** opposite to a securing portion **667** in a coaxial manner. The drive shaft **91** is supported in a reciprocally movable manner in an axial direction. The drive shaft **91** receives a restoring force of inner spring mounted in the drive source **90** and an electromagnetic force generated by the electromagnetic solenoid. The drive shaft **91** is inserted into one of the drain port **666** formed in the sleeve **66**, and always come in contact with an axial end of the spool **70**. The drain port **666** receiving the drive shaft **91** may be referred to as the drain port **666***a*. The driving source **90** generates the driving force in accordance with a current that is supplied as an instruction value from the control circuit **96** to the solenoid coil in the driving source **90**. The driving force drives and pushes the spool **70** in the axial forward direction Dg shown in FIG. **4** via the drive shaft **91**. The driving force drives the spool **70** only toward the axial forward direction.

As shown in FIGS. **4**-**8**, a first resilient member **80** made of a metal compression coil spring is coaxially accommodated in the sleeve **66**. The first resilient member **80** is deformed by compressing it by disposing it between the securing portion **667** of the sleeve **66** and an axial end part of the spool **70** close to the securing portion **667**. Thereby, the first resilient member **80** generates a first restoring force F**1** which pushes and biases the spool **70** in the axial reverse direction Dr. The first resilient member **80** generates the first restoring force F**1** for pushing the spool **70** in the axial direction Dr, when the spool **70** is in either the first region or the second region.

A second resilient member **82** made of a metal compression coil spring is coaxially accommodated in the drain port **666***a* of the sleeve **66**. The second resilient member **82** is deformed by compressing it by disposing it between the seat portion **669** provided by the drain port **666***a* and the movable member **84**. Thereby, the second resilient member **82** generates a second restoring force F**2** which pushes and biases the spool **70** in the axial reverse direction Dr. The second resilient member **82** generates the second restoring force F**2** for pushing the movable member **84** in the axial direction Dr when the spool **70** is in either the first region or the second region. The first resilient member **80** and the second resilient member **82** generate the first restoring force F**1** and the second restoring force F**2**, respectively, which both push the spool **70** in the reverse direction opposite to the forward direction.

The movable member **84** is capable of being engaged with the spool **70** in the first region to move together with the spool **70**. The movable member **84** is capable of resting on the sleeve in the second region to enable the spool **70** to move freely relative to the movable member **84**.

The movable member **84** is made of metal, and is formed in a cylindrical shape with a step. The movable member **84** is disposed in and accommodated in the drain port **666***a* in the sleeve **66** in a coaxial manner with the drain port **666***a*. The movable member **84** is supported in a reciprocally movable manner in the axial forward direction Dg and the axial reverse direction Dr. The movable member **84** includes a small diameter portion **840** which provides an innermost portion. A part of the spool **70** provides a bush **706** which is made of metal and is formed in a cylindrical shape with a flange.

The small diameter portion **840** is coupled on the bush **706**. The movable member **84** is supported from a radial inside by an outer circumferential surface of the bush **706** in a slidable manner. In other words, the spool **70** supports the movable member **84** via the innermost portion **840** of the movable member **84**. The movable member **84** includes a large diameter portion **841** which provides an outermost portion. The large diameter portion **841** is freely inserted in the drain port **666***a* in a coaxial manner. The large diameter portion **841** is distanced from the inner surface of the drain port **666***a* and is kept apart from the inner surface of the drain port **666***a*. The movable member **84** is supported by the spool **70** in a manner that the movable member **84** is apart from the sleeve **66** in a radial direction. The movable member **84** is supported on the spool **70** via a supporting portion between the movable member **84** and the spool **70**. The supporting portion is provided by an inner surface and an outer surface. A radial gap Gsl is provided between the movable member **84** and the sleeve **66**. A radial gap Gsp is defined on the supporting portion. As shown in FIGS. **9**A and **9**B, the radial gap Gsl is wider than the radial gap Gsp. Therefore, the movable member **84** is supported on the spool **70** via the supporting portion in a manner that the radial gap Gsl is wider than the radial gap Gsp. In FIGS. **9**A and **9**B, in order to make an understanding of explanation easy, the radial gap Gsp is illustrated widely emphasized.

The sleeve **66** has a stopper **660** fixed on the drain port **666***a* as a part thereof. The stopper **660** is made of metal and is formed in a circular plate shape. As shown in FIGS. **4**-**9**, the large diameter portion **841** is disposed on the movable member **84** so that the large diameter portion **841** may be rest on the stopper **660** in the axial reverse direction Dr, and may be apart from the stopper **660** in the axial forward direction Dg. The movable member **84** has a stepped portion **842** that connects the small diameter portion **840** and the large diameter portion **841**. The flange formed on the bush **706** provides a stopper **707** on the spool **70**. The stepped portion **842** is disposed on the movable member **84** so that the stepped portion **842** may be rest on the stopper **707** in the axial reverse direction Dr, and may be apart from the stopper **707** in the axial forward direction Dg. The stepped portion **842** receives the second restoring force F**2** in the axial reverse direction Dr by engaging the end of the second resilient member **82**. In other words, the end of the second resilient member **82** opposite to the seat portion **669** rests on the stepped portion **842**. The movable member **84** provides two states and switches those two states. As shown in FIG. **9**A, in one state, the movable member **84** rests on the sleeve **66** by resting the large diameter portion **841** on the stopper **660** in the axial direction. In this state, since the large diameter portion **841** is firmly pressed onto the stopper **660**, the movable member **84** is also held to the radial direction. As shown in FIG. **9**B, in the other state, the movable member **84** is engaged with the spool **70** by engaging the stepped portion **842** on the stopper **707** in the axial direction. As shown in FIG. **4**, the stopper **660** also works as a portion on which the stopper **707** rests when the spool **70** reaches to the end RO in the axial reverse direction Dr.

In the lock region Rl shown in FIGS. **4** and **5**, the movable member **84** rests on the stopper **660** by the second restoring force F**2** of the second resilient member **82**. The stopper **707** is disengaged and distanced from the movable member **84** in the axial reverse direction Dr, and the movable member **84** enables the spool **70** to move relatively and freely from the movable member **84**. The movable member **84** rests on the sleeve **66** in the lock region Rl, i.e., the second region, to disable the second restoring force F**2** to act on the spool **70**. In other words, the biasing to the sleeve **70** by the second restoring force F**2** is restricted in the lock region Rl. In the lock region Rl, the spool **70** is biased by the first restoring force F**1** alone. Therefore, in the lock region Rl, only the first restoring force F**1** alone acts independently on the sleeve **70** as the biasing force that biases the spool **70** in the axial reverse direction Dr, as shown in FIG. **11**. When no driving force is applied from the driving source **90** to the spool **70**, the spool **70** moves to the end position RO of the lock region Rl in the axial reverse direction Dr as shown in FIG. **4**. In this state, the stopper **707** rests on the stopper **660** of the sleeve **66**.

In the regions Ra, Rh, Rr shown in FIGS. **6**, **7**, and **8**, the movable member **84** engages with the stopper **707** on the spool **70** by the second restoring force F**2**, and moves together with the spool **70**. Therefore, the movable member **84** can be lifted and apart from the stopper **660** of the sleeve **66**. The movable member **84** engages with the spool **70** in the regions Ra, Rh, Rr, i.e., the first region, to enable the second restoring force F**2** to act on the spool **70**. In other words, the spool **70** is biased by both the first restoring force F**1** and the second restoring force F**2** in the axial reverse direction Dr. Therefore, in the regions Ra, Rh, and Rr, a summed force of the first restoring force F**1** and the second restoring force F**2** acts on the sleeve **70** as the biasing force that biases the spool **70** in the axial reverse direction Dr, as shown in FIG. **11**.

Accordingly, the biasing force may be changed in a step like manner as shown in FIGS. **10**A, **10**B, and **11**. This is caused by switching acting force at a boundary position between the rock region Rl and the advance region Ra. The acting force is switched between the summed force of the second restoring force F**2** and the first restoring force F**1**, and a single force of the first restoring force F**1**. As shown in FIG. **11**, a width W**1** of the step like change is set greater than an estimated value of a product variation in driving force which is applied to the spool **70** at the boundary position between the rock region Rl and the advance region Ra from the driving source **90**. Accordingly, it is possible to balance the driving force within the estimated value range and the biasing force within the width W**1** of the biasing force. The spool position of the spool **70** may be determined based on a balance between the driving force and the biasing force. For example, the spool positions are shown in FIG. **11** by crossing points of a solid line and dashed lines. Therefore, among those spool positions, the spool position at the boundary position between the regions Rl and Ra will not be dependent on the product variation of the driving source **90**, and will be dependent only on the product variation of the biasing device, such as the movable member **84**. Therefore, even if the driving force is varied for the products, it is still possible to drive the spool **70** to the boundary position, which is defined by the mechanical structure relating to the movable member **84**, by a predetermined instruction value. In addition, it is possible to provide required characteristics in the regions Rl and Ra on both sides to the boundary position by obtaining certain differences on both the driving force and the instruction value at the boundary position. In this embodiment, the advancing region Ra corresponds to the first region, and the lock region Rl corresponds to the second region.

(Operation)

Next, operation of the variable valve timing device **1** is explained.

(1) Lock Operation

When the internal combustion engine is at stop state, starting state, or idling state, the pressure of hydraulic oil is relatively low. The control circuit **96** energizes the solenoid of the driving source **90** to drive the control valve **60**, so that the spool **70** moves to be positioned in the lock region Rl as shown in FIGS. **4** and **5**.

The advancing port **661** communicated with the advancing chambers **22**, **23**, **24** through the passages **41**, **42**, **43**, **44** is fluidly connected to the main-supply port **664** communicated with the pump **4** through the passages **3**, **54**. The hydraulic oil supplied from the pump **4** is introduced into the advancing chambers **22**, **23**, **24**. Simultaneously, the retarding port **662** communicated with the retarding chambers **26**, **27** **28** through the passages **45**, **46**, **47**, **48** is fluidly connected to the discharge port **666** communicated with the passage **54** through the passage **705**. The hydraulic oil in the retarding chambers **26**, **27**, **28** is discharged. Moreover, the lock release port **663** communicated with the lock release chamber **17** through the passage **49** is fluidly connected to the discharge port **666** communicated with the passage **54** through the passage **705**. The hydraulic oil in the lock release chamber **17** is discharged.

As described above, when the spool **70** is in the lock range Rl, it is possible perform a lock of phase at the lock phase certainly. The lock is performed by introducing a small amount of the hydraulic oil into the advancing chambers **22**, **23**, **24**, discharging the hydraulic oil from the retarding chambers **26**, **27**, **28**, and discharging the hydraulic oil from the lock release chamber **17**. When a rotation of the internal combustion engine is stopped, supplying of the hydraulic oil by the pump **4** and generating of the drive force by the drive source **90** are also stopped. Even in such stopping condition, since the first restoring force F**1** acts on the spool **70** as the biasing force, discharging of the hydraulic oil from the lock release chamber **17** is performed at the end position RO in the axial reverse direction Dr. In such stopping condition, the vane rotor **14** still receives the restoring force of the assist spring **18** in the advancing direction and the fluctuation torque shifted in the retarding direction in average, therefore, the rotational phase may be changed and may be reached to the regulated phase region. Then, the lock member **16** can be inserted into the regulated hole **131** and restrict the rotational phase within the regulated phase region. Further, the lock member **16** may be inserted into the lock hole **130**. According to the embodiment, the lock member **16** may be easily engaged with the lock hole **130** in the lock phase within the regulated phase region. Therefore, it is possible to move the variable valve timing device to the lock phase certainly within a period of time until a rotation of the internal combustion engine is completely stopped.

(2) Advancing Operation

When the internal combustion engine satisfies an operational condition in which an actual phase is on a retarding side more than a permissible difference from a target phase, the control circuit **96** energizes the solenoid of the driving source **90** to drive the control valve **60**, so that the spool **70** moves to be positioned in the advancing region Ra as shown in FIG. **6**.

As a result, the advancing port **661** communicated with the advancing chambers **22**, **23**, **24** through the passages **41**, **42**, **43**, **44** is fluidly connected to the main-supply port **664** communicated with the pump **4** through the passages **3**, **50**. The hydraulic oil supplied from the pump **4** is introduced into the advancing chambers **22**, **23**, **24** with relatively large amount compare to the lock operation. Simultaneously, the retarding port **662** communicated with the retarding chambers **26**, **27** **28** through the passages **45**, **46**, **47**, **48** is fluidly connected to the discharge port **666** communicated with the passage **54** through the passage **705**. The hydraulic oil in the retarding chambers **26**, **27**, **28** is discharged. Moreover, the lock release port **663** communicated with the lock release chamber **17** through the passage **49** is fluidly connected to the sub-supply port **665** communicated with the pump **4** through the passages **3**, **50**, **52**. The hydraulic oil is introduced into the lock release chamber **17**.

As described above, when the spool **70** is in the advancing range Ra, the hydraulic oil is introduced into the lock release chamber **17** to unlock the phase, a large amount of the hydraulic oil is introduced into the advancing chambers **22**, **23**, **24** and the hydraulic oil is discharged from the retarding chambers **26**, **27**, **28**. Accordingly, it is possible to change the valve timing promptly. It is possible to improve response of the VVT in the advancing direction.

(3) Holding Operation

When the internal combustion engine satisfies an operational condition in which an actual phase is within a permissible difference from a target phase, the control circuit **96** energizes the solenoid of the driving source **90** to drive the control valve **60**, so that the spool **70** moves to be positioned in the holding region Rh as shown in FIG. **7**.

As a result, since the advancing port **661** is disconnected from the other ports, the hydraulic oil in the advancing chambers **22**, **23**, **24** is kept therein. Simultaneously, since the retarding port **662** is also disconnected from the other ports, the hydraulic oil in the retard chambers **26**, **27**, **28** is kept therein. In addition, the lock release port **663** is fluidly connected to the sub-supply port **665**, so that the hydraulic oil is introduced into the lock release chamber **17**.

As described above, when the spool **70** is in the holding range Rh, the hydraulic oil is introduced into the lock release chamber **17** to unlock the phase, and the hydraulic oil is kept in both the advancing chambers **22**, **23**, **24** and the retarding chambers **26**, **27**, **28**. Accordingly, it is possible to hold the valve timing within a fluctuation of phase caused by the fluctuation torque.

(4) Retarding Operation

When the internal combustion engine satisfies an operational condition in which an actual phase is on an advancing side more than a permissible difference from a target phase, the control circuit **96** energizes the solenoid of the driving source **90** to drive the control valve **60**, so that the spool **70** moves to be positioned in the retarding region Rr as shown in FIG. **8**.

The advancing port **661** communicated with the advancing chambers **22**, **23** **24** through the passages **41**, **42**, **43**, **44** is fluidly connected to the drain port **666** communicated with the passage **54** through the passage **705**. The hydraulic oil in the advancing chambers **22**, **23**, **24** is discharged. The retarding port **662** communicated with the retarding chambers **26**, **27**, **28** through the passages **45**, **46**, **47**, **48** is fluidly connected to the main-supply port **664** communicated with the pump **4** through the passages **3**, **50**. The hydraulic oil supplied from the pump **4** is introduced into the retarding chambers **26**, **27**, **28** with relatively large amount similar to the advancing operation. The lock release port **663** is fluidly connected to the sub-supply port **665**, so that the hydraulic oil is introduced into the lock release chamber **17**.

As described above, when the spool **70** is in the retarding range Rr, the hydraulic oil is introduced into the lock release chamber **17** to unlock the phase, a large amount of the hydraulic oil is introduced into the retarding chambers **26**, **27**, **28** and the hydraulic oil is discharged from the advancing chambers **22**, **23**, **24**. Accordingly, it is possible to change the valve timing promptly. It is possible to improve response of the VVT in the retarding direction.

(Advantages)

As described above, according to the first embodiment, the control valve **60** can provide a step like change of the biasing force acting on the spool **70** at the boundary position between the lock region Rl and the advancing region Ra. Required characteristics in the regions Rl and Ra are definitely switched according to the spool position. For example, in the lock region Rl, it is required to perform a lock and unlock operation properly. In the advancing region Ra, it is required to perform an advancing operation properly. According to the control valve **60**, it is possible to perform required characteristics in regions respectively.

As shown in FIGS. **9**A and **9**B, the movable member **84** is distanced inwardly from the sleeve **66** by a wide gap Gsl. In the advance region Ra where the movable member **84** and the spool **70** are axially engaged and move together, the movable member **84** can move without contacting radially with the sleeve **66**. Therefore, the spool **70**, which is engaged with the movable member **84**, receives a sliding resistance that is reduced to a certain low level.

Since the movable member **84** is supported on the spool **70** via the small diameter portion **840**, it is possible to reduce a radius for supporting the movable member **84**. As a result, a moment generated when the movable member **84** is inclined and pushed toward the spool **70** by a radial side force could not easily become large. Even if the movable member **84** receives a side force in the radial direction by inclining the acting direction of the second restoring force F**2** from the axial direction of the sleeve **66**, since it is possible to suppress pushing to the spool **70**, a movement resistance acting on the spool **70** may be kept small.

FIG. **12** shows a relationship between a spool position and the instruction value to the driving source **90**. As shown in FIG. **12**, in the second region, there may be a small amount of hysteresis on the spool position between a movement in an axial forward direction Dg and a movement in an axial reverse direction Dr. In addition, as shown in FIG. **12**, the hysteresis reduction effect may be also performed by the similar principle in the holding region Rh and the retarding region Rr. The holding region Rh and the retarding region Rr are defined on a side of the advancing region Ra that is one side while the lock region Rl is defined on the opposite other side of the advancing region Ra.

In addition, the movable member **84** is supported by the spool **70** from the radial inside. Therefore, in the lock region Rl where the movable member **84** rests on the sleeve **66**, since the spool **70** can move relative to the movable member **84** during contacting the movable member **84** in a radial direction, the spool **70** receives a movement resistance corresponding to a sliding resistance between the components, such as the spool **70** and the movable member **84**. Since the movable member **84** is in the state where the movable member **84** rests on and pushed against the stopper **660** of the sleeve **66** by the second restoring force F**2** of the second resilient member **82**, a pushing force on the movable member **84** toward the spool **70** caused by a radial side force may be suppressed. Therefore, the sliding resistance which is generated between the spool **70** and the movable members **84** and acts on the spool **70** may become small. In this embodiment, the movable member **84** has a cylindrical inside surface on the small diameter portion **840** that is supported on a spool outside surface of the spool **70** in a slidable manner. The movable member **84** rests on the sleeve **66** via a circular end thereof to keep the cylindrical inside surface parallel to the spool outside surface. Therefore, it is possible to keep a sliding resistance low and stable.

As shown in FIG. **12**, which shows a relationship between a spool position and the instruction value to the driving source, in the lock region Rl where the movement resistance may become low, there may be a small amount of hysteresis between a movement in the axial forward direction Dg and a movement in the axial reverse direction Dr. In addition, since a fluctuation of friction between the spool **70** and the movable member **84** is reduced to a sufficiently low level, it is possible to suppress a stick-slip in the lock region Rl.

As mentioned above, according to the first embodiment which can suppress the hysteresis and the stick slip about the spool position, it is possible to perform a high suppressing effect about the variation in the response characteristic of the control valve **60** resulting from the movement resistance of the spool **70**.

Second Embodiment

As shown in FIG. **13**, the second embodiment is a modification of the first embodiment.

(Drive Mechanism)

Hereafter, components of a control valve **260** in the second embodiment that are different from the first embodiment are mainly explained. As shown in FIGS. **13**-**17**, the biasing device includes a first resilient member **80** and a second resilient member **282**. The second resilient member **282** made of a metal compression coil spring is coaxially accommodated in the drain port **666***a* of the sleeve **266** disposed within the rotary components **2**, **14**. The second resilient member **82** is deformed by compressing it by disposing it between the stopper **660** fixed on the drain port **666***a* and the movable member **284**. Thereby, the second resilient member **282** generates a second restoring force F**2** which pushes and biases the movable member **284** in the axial forward direction Dg. The second resilient member **82** generates the second restoring force F**2** for pushing the movable member **284** in the axial direction Dg when the spool **270** is in either the first region or the second region.

The biasing device includes the movable member **284**. The movable member **284** is made of metal, and is formed in a cylindrical shape with a flange. The movable member **284** is disposed in and accommodated in the drain port **666***a* in the sleeve **266** in a coaxial manner with the drain port **666***a*. The movable member **284** is supported in a reciprocally movable manner in the axial forward direction Dg and the axial reverse direction Dr. The movable member **284** includes a main-cylindrical portion **2840** which provides an innermost portion, i.e., a small diameter portion. A part of the spool **270** provides an axial end portion **2706**, i.e., a bush. The main-cylindrical portion **2840** is coupled on the axial end portion **2706**. The movable member **284** is supported from a radial inside by an outer circumferential surface of the axial end portion **2706** in a slidable manner. In other words, the spool **270** supports the movable member **284** via the main-cylindrical portion **2840** of the movable member **84**. The movable member **84** includes a flange portion **2841** which provides an outermost portion, a large diameter portion. The flange portion **2841** is freely inserted in the drain port **666***a* in a coaxial manner. The flange portion **2841** is inwardly distanced from the inner surface of the drain port **666***a* and is kept apart from the inner surface of the drain port **666***a*. The movable member **284** is supported by the spool **270** in a manner that the movable member **284** is apart from the sleeve **266** in a radial direction. The movable member **284** is supported on the spool **270** via a supporting portion between the movable member **284** and the spool **270**. The supporting portion is provided by an inner surface and an outer surface. A radial gap Gsl is provided between the flange portion **2841** and the sleeve **266**. A radial gap Gsp is defined on the supporting portion. The radial gap Gsp corresponds to a gap enabling sliding motion. As shown in FIGS. **18**A and **18**B, the radial gap Gsl is wider than the radial gap Gsp. Therefore, the movable member **284** is supported on the spool **270** via the supporting portion in a manner that the radial gap Gsl is wider than the radial gap Gsp. In FIGS. **18**A and **18**B, in order to make an understanding of explanation easy, the radial gap Gsp is illustrated widely emphasized.

The sleeve **266** has a stopper **2660** formed on the drain port **666***a* as a part thereof. The stopper **2660** is formed in a circular plan shape. As shown in FIGS. **13**-**18**, the flange **2841** is disposed on the movable member **284** so that the flange **2841** may be rest on the stopper **2660** in the axial forward direction Dg, and may be apart from the stopper **2660** in the axial reverse direction Dr. The spool **270** provides a stopper **2707** by an axial end **2706** thereof. The stopper **2707** is formed in a circular plan shape. The flange **2841** is disposed on the movable member **284** so that the flange may be rest on the stopper **2707** in the axial forward direction Dg, and may be apart from the stopper **2707** in the axial reverse direction Dr. The flange **2841** receives the second restoring force F2 in the axial forward direction Dg by engaging the end of the second resilient member **282**. In other words, the end of the second resilient member **282** opposite to the stopper **660** rests on the flange **2841**. The movable member **284** provides two states and switches those two states. As shown in FIG. **18**B, in one state, the movable member **284** rests on the sleeve **266** by resting the flange **2841** on the stopper **2660** in the axial direction. In this state, since the flange **2841** is firmly pressed onto the stopper **2660**, the movable member **284** is also held to the radial direction. As shown in FIG. **18**A, in the other state, the movable member **284** is engaged with the spool **270** by engaging the flange **2841** on the stopper **2707** in the axial direction. As shown in FIG. **13**, the stopper **660** also works as a portion on which the stopper **2707** rests via the movable member **284** when the spool **270** reaches to the end RO in the axial reverse direction Dr.

In the lock region Rl shown in FIGS. **13** and **17**, the movable member **284** engages with the stopper **2707** on the spool **270** by the second restoring force F2 in the axial forward direction Dg generated by the second resilient member **282**, and moves together with the spool **270**. Therefore, the movable member **284** can be lifted and apart from the stopper **2660** of the sleeve **266**. As shown in FIG. **19**, in the lock region Rl of the second embodiment, the second restoring force F2 is adjusted smaller than the first restoring force F1 of the first resilient member **80** which acts on the counter direction Dr. The first resilient member **80** generates the first restoring force F1 which pushes the spool **270** in the reverse direction opposite to the forward direction. The second resilient member **282** generates the second restoring force F2 that pushes the spool **270** in the forward direction and is smaller than the first restoring force F1 in the first region. In other words, the spool **270** is biased in the axial reverse direction Dr by acting the first restoring force F1 that is greater than the second restoring force F2. Therefore, in the lock region Rl, a summed force of the first restoring force F1 and the second restoring force F2, i.e., a differential force of the first restoring force F1 and the second restoring force F2, acts on the sleeve **270** as the biasing force that biases the spool **270** in the axial reverse direction Dr, as shown in FIG. **19**. In this second embodiment, the movable member **284** is supported on the spool **270** via a supporting portion, i.e., the main-cylindrical portion **2840**. The main-cylindrical portion **2840** has a supporting radius "ϕ (Phi)" and an axial supporting length "L" in the lock region Rl, i.e., the first region as shown in FIG. **18**A. The axial supporting length L is the same as the maximum supporting length in the advancing region Ra. The supporting radius "ϕ (Phi)" is smaller than the axial supporting length "L" when the spool **270** is in the lock region Rl.

When no driving force is applied from the driving source **90** to the spool **270**, the spool **270** moves to the end position RO of the lock region Rl in the axial reverse direction Dr as shown in FIG. **13**. In this state, the stopper **2707** rests on the stopper **660** of the sleeve **266** via the movable member **284**. Therefore, in a case that the lock operation similar to the first embodiment is performed when a rotation of the internal combustion engine is stopped, since a summed force of the first and the second restoring force F1 and F2 act on the spool **270** as the biasing force, discharging of the hydraulic oil from the lock release chamber **17** is performed at the end position RO in the axial reverse direction Dr. Therefore, similar to the first embodiment, it is possible to move the variable valve timing device to the lock phase certainly within a period of time until a rotation of the internal combustion engine is completely stopped.

In the regions Ra, Rh, Rr shown in FIGS. **15**, **16**, and **17**, the movable member **284** rests on the stopper **2660** by the second restoring force F2 of the second resilient member **282**. The stopper **2707** is disengaged and distanced from the movable member **284** in the axial forward direction Dg, and the movable member **284** enables the spool **270** to move relatively and freely from the movable member **284**. In other words, the biasing to the sleeve **270** by the second restoring force F2 is restricted in the regions Ra, Rh, Rr. In the regions Ra, Rh, Rr, the spool **270** is biased by the first restoring force F1 alone. Therefore, in the regions Ra, Rh, Rr, only the first restoring force F1 alone acts independently on the sleeve **270** as the biasing force that biases the spool **270** in the axial reverse direction Dr, as shown in FIG. **19**.

Accordingly, the biasing force may be changed in a step like manner as shown in FIG. **19**. This is caused by switching acting force at a boundary position between the rock region Rl and the advance region Ra. The acting force is switched between the summed force of the second restoring force F2 and the first restoring force F1, and a single force of the first restoring force F1. Similar to the first embodiment, a width W2 of the step like change is set greater than an estimated value of a product variation in driving force which is applied to the spool **70** at the boundary position between the rock region Rl and the advance region Ra from the driving source **90**. Therefore, the boundary position is dependent only on the product variation of the biasing device, such as the movable member **284**. In this embodiment, the lock region Rl corresponds to the first region, and the advancing region Ra corresponds to the second region.

(Advantages)

As described above, according to the second embodiment, the control valve **260** can provide a step like change of the biasing force acting on the spool **70** at the boundary position between the lock region Rl and the advancing region Ra. Required characteristics in the regions Rl and Ra are definitely switched by the spool position at the boundary position. For example, in the lock region Rl, it is required to perform a lock and unlock operation properly. In the advancing region

Ra, it is required to perform an advancing operation properly. According to the control valve **260**, it is possible to perform required characteristics in both regions respectively.

As shown in FIGS. **18**A and **18**B, the movable member **284** is radially distanced from the sleeve **266** by the large gap Gsl. In the lock region Rl where the movable member **284** and the spool **270** are axially engaged and move together, the movable member **284** can move without contacting radially with the sleeve **266**. Therefore, the spool **270**, which is engaged with the movable member **284**, receives a sliding resistance that is reduced to a certain low level.

Since the movable member **284** supported by the supporting radius is small enough for becomes small about the movable member **284** by which the body cylinder part **2840** of the "innermost portion" is supported by the spool **270**, the moment generated in the direction which inclines according to the side force of the path direction, and is forced on the spool **70** cannot become large easily. Since the movable member **284** and the spool **270** provide the supporting radius "ϕ (Phi)" that is smaller than the axial supporting length L in the lock region Rl, the movable member may not be easily inclined. Even if the movable member **284** receives a side force in the radial direction by inclining the acting direction of the second restoring force F**2** from the axial direction of the sleeve **266**, since it is possible to suppress pushing to the spool **270**, a movement resistance acting on the spool **270** may be kept small.

In this embodiment, it is also possible to suppress an amount of hysteresis in a similar way of the first embodiment. In the lock region Rl where the movement resistance on the spool **270** is kept small, there may be a small amount of hysteresis on the spool position between a movement in the axial forward direction Dg and a movement in the axial reverse direction Dr.

In addition, the movable member **284** is supported by the spool **270** from the radial inside. Therefore, in the advance region Ra where the movable member **284** rests on the sleeve **266**, since the spool **270** can move relative to the movable member **284** during contacting the movable member **284** in a radial direction, the spool **270** receives a movement resistance corresponding to a sliding resistance between the components, such as the spool **270** and the movable member **284**. Since the movable member **284** is in the state where the movable member **284** rests on and pushed against the stopper **2660** of the sleeve **266** by the second restoring force F**2** of the second resilient member **282**, a pushing force on the movable member **284** toward the spool **270** caused by a radial side force may be suppressed. Therefore, the sliding resistance which is generated between the spool **270** and the movable member **284** and acts on the spool **270** may become small.

In this embodiment, it is also possible to suppress an amount of hysteresis in a similar way of the first embodiment. In the advance region Ra where the movement resistance on the spool **270** is kept small, there may be a small amount of hysteresis on the spool position between a movement in the axial forward direction Dg and a movement in the axial reverse direction Dr. In addition, since a fluctuation of friction between the spool **270** and the movable member **284** is reduced to a sufficiently low level, it is possible to suppress a stick-slip in the advance region Ra. The hysteresis reduction effect and the stick slip reduction effect may be also performed in the holding region Rh and the retarding region Rr. The holding region Rh and the retarding region Rr are defined on a side of the advancing region Ra that is one side while the lock region Rl is defined on the opposite other side of the advancing region Ra.

As mentioned above, according to the second embodiment which can suppress the hysteresis and the stick slip about the spool position, it is possible to perform a high suppressing effect about the variation in the response characteristic of the control valve **260** resulting from the movement resistance of the spool **270**.

Other Embodiments

Although the present invention is described based on the illustrated embodiments, the present invention should not be limited to such embodiments illustrated, may be implemented in other ways and be applied to any combinations and modifications without departing from the scope of the invention.

For example, in the first and second embodiments, a switching position where the biasing force to the spool **70**, **270** against the driving force of the driving source **90** is switched in a step like manner is set on a boundary position between the region Rl and the region Ra. In stead of the above arrangement, the switching position may be set on a boundary position between the region Ra and the region Rh. In addition, the switching position may be set on a boundary position between divided partial regions provided by dividing one of the regions Rl, Ra, Rh, Rr. In those embodiments, one of the first region and the second region includes a region in which the vane rotor is controlled to change the rotational phase. The other one of the first region and the second region includes a region in which the vane rotor is controlled to lock the rotational phase in a middle phase between a most advanced phase and a most retarded phase.

In the embodiments, the movable members **84** and **284** are supported at the portions **840** and **2840** provided as the innermost portions. However, the movable members may be supported at portions placed radial outer side than the innermost portions by the spools **70** and **270**. In the first embodiment, the supporting radius of the movable member **84** by the spool **70** is set a value equal to, or larger than the axial supporting length in the region when the movable member **84** and the spool **70** move together. However, the supporting length may be set a value smaller than the supporting length similar to the second embodiment. In the second embodiment, the supporting radius of the movable member **284** by the spool **270** may be set a value equal to or larger than the axial supporting length in the region when the movable member **284** and the spool **270** move together. The axial supporting length of the movable member **284** by the spool **270** is variable when the movable member **284** enables the spool **270** to move relative to the movable member **284**.

In the first and second embodiment, the sleeve **66**, **266**, which accommodates the spool **70**, **270**, the resilient member **80**, **82**, **282**, and the movable member **84**, **284**, are accommodated within the rotary components **2**, **14**. In stead of the above arrangement, the sleeve **66**, **266** may be disposed within one component of the rotary components **2**, **14**. In addition, the sleeve **66**, **266** may be disposed axial or radial outside of the rotary components **2**, **14**. FIGS. **20**A and **20**B show a modification of the first embodiment. A circular-plate-shaped snap ring **3707** may be attached on the spool **70** as an alternative part acting as the bush **706** which is formed in a cylindrical shape with a flange. In this case, a small diameter portion **840** of the movable member **84** is supported from a radial inside with a radial gap Gsp by the axial end part **3706** of the spool **70**. In addition, the movable member **84** has the stepped portion **842** that is disposed to be possible to be engaged with the snap ring **3707** in the axial reverse direction Dr, and to be apart from the snap ring **3707** in the axial forward direction Dg.

In addition, in the first and second embodiment, the lock phase is set at the middle position between the most retarded phase and the most advanced phase. However, instead of the above arrangement, the lock phase may be set at the most retarded phase or the most advanced phase. In such arrangements, it is possible to eliminate components for pushing the vane rotor **14** by the assist spring **18**. In the embodiments, the regulated hole **131** is formed to define the regulated phase region. Alternatively, the present invention may be applied to a device that has no regulated hole **13**. In addition, the present invention may be applied to a device that has a plurality of lock members which are provided by dividing the lock member **16** and are biased by lock springs **19** respectively.

In the embodiment, the present invention is applied to the device for varying the valve timing of the intake valve. The present invention may be applied to a device for varying the valve timing of an exhaust valve, or a device for varying the valve timing of both the intake valve and the exhaust valve.

Although the present invention has been fully described in connection with the preferred embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being within the scope of the present invention as defined by the appended claims.

What is claimed is:

1. A variable valve timing device for adjusting a valve timing of a valve being opened/closed by a camshaft which is driven by a torque transmitted from a crankshaft of an internal combustion engine, the variable valve timing device comprising:

a housing defining a hydraulic chamber therein;

a vane rotor disposed to define an advancing chamber and a retarding chamber by dividing the hydraulic chamber in a rotational direction, the vane rotor being rotatable to change a rotational phase relative to the housing in response to hydraulic fluid introduced into one of the advancing chamber and the retarding chamber;

a control valve having a sleeve and a spool disposed in the sleeve in a reciprocally movable manner, the control valve being adapted to control in-flow and out-flow of the hydraulic fluid with respect to both the advancing chamber and the retarding chamber by adjusting a spool position in an axial direction;

a driving source which changes the spool position by generating a driving force of the spool in response to an instruction value; and

a biasing device which generates and adjusts a biasing force biasing the spool against the driving force, wherein

the control valve provides a first region and a second region arranged along the axial direction in a region where the spool is movable, and wherein

the biasing device includes:

a movable member which is capable of being engaged with the spool in the first region to move together with the spool, and is capable of resting on the sleeve in the second region to enable the spool to move relative to the movable member;

a first resilient member which generates a first restoring force for pushing the spool in the axial direction when the spool is in both the first region and the second region; and

a second resilient member which generates a second restoring force for pushing the movable member in the axial direction when the spool is in both the first region and the second region, wherein

the movable member engages with the spool in the first region to enable the second restoring force to act on the spool, and rests on the sleeve in the second region to disable the second restoring force to act on the spool, and wherein

the movable member is supported by the spool in a manner that the movable member is apart from the sleeve in a radial direction.

2. The variable valve timing device in claim **1**, wherein the movable member is formed in a cylindrical shape.

3. The variable valve timing device in claim **2**, wherein the movable member is supported from a radial inside thereof by the spool.

4. The variable valve timing device in claim **3**, wherein the movable member has a cylindrical inside surface that is supported on a spool outside surface of the spool in a slidable manner, and

the movable member rests on the sleeve via a circular end thereof to keep the cylindrical inside surface parallel to the spool outside surface.

5. The variable valve timing device in claim **1**, wherein the movable member is supported on the spool via a supporting portion between the movable member and the spool in a manner that a radial gap between the movable member and the sleeve is wider than a radial gap defined on the supporting portion.

6. The variable valve timing device in claim **1**, wherein the spool supports the movable member via the innermost portion of the movable member.

7. The variable valve timing device in claim **1**, wherein the movable member is supported on the spool via a supporting portion which has a supporting radius and an axial supporting length, the supporting radius being smaller than the axial supporting length when the spool is in the first region.

8. The variable valve timing device in claim **1**, wherein the driving source generates the driving force that drives the spool only toward a forward direction in the axial direction, and wherein

the first resilient member and the second resilient member generate the first restoring force and the second restoring force, respectively, which both push the spool in a reverse direction opposite to the forward direction.

9. The variable valve timing device in claim **1**, wherein the driving source generates the driving force that drives the spool only toward a forward direction in the axial direction, and wherein

the first resilient member generates the first restoring force which pushes the spool in a reverse direction opposite to the forward direction, and wherein

the second resilient member generates the second restoring force that pushes the spool in the forward direction and is smaller than the first restoring force in the first region.

10. The variable valve timing device in claim **1**, wherein one of the first region and the second region includes a region in which the vane rotor is controlled to change the rotational phase, and

the other one of the first region and the second region includes a region in which the vane rotor is controlled to lock the rotational phase in a middle phase between a most advanced phase and a most retarded phase.

11. The variable valve timing device in claim **1**, wherein the first resilient member and the second resilient member are disposed in the sleeve.

12. The variable valve timing device in claim **1**, wherein the housing is adapted to rotate synchronously with the crankshaft, and the vane rotor is adapted to rotate synchronously with the camshaft.

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